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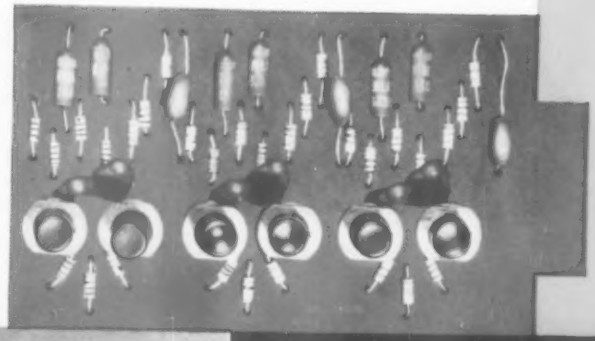

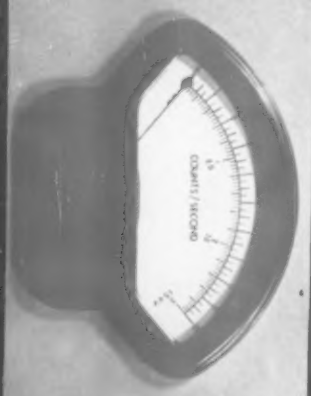

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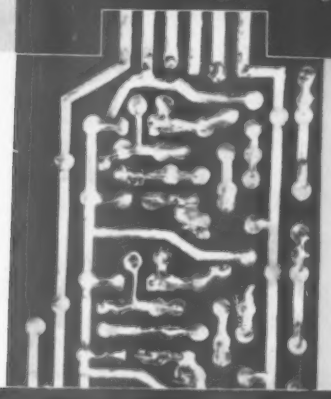

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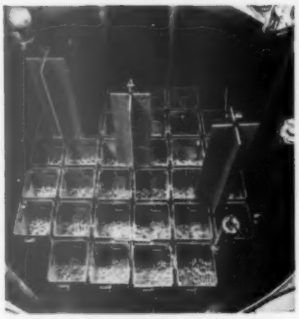

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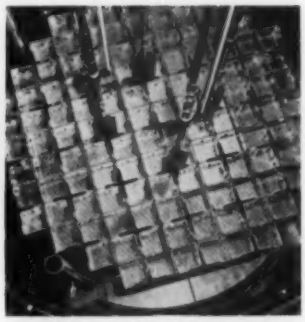

Critical experiment core for the thorium converter reactor designed and being built by B&W for the Consolidated Edison Company of New York (Indian Point).

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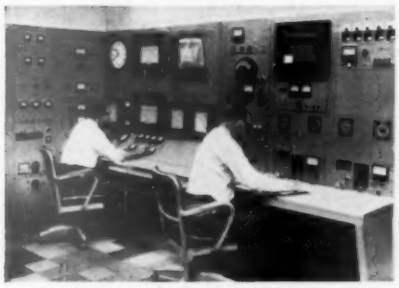

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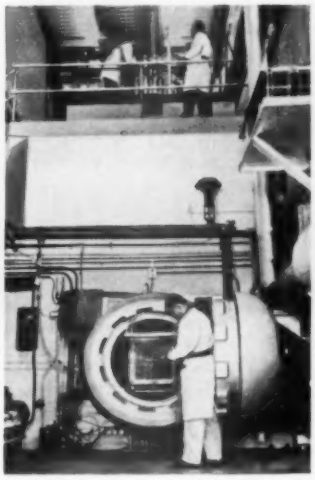

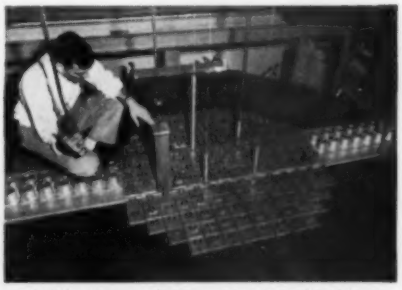

Critical experiment core for the Liquid Metal Fuel Reactor Experiment (LMFRE).

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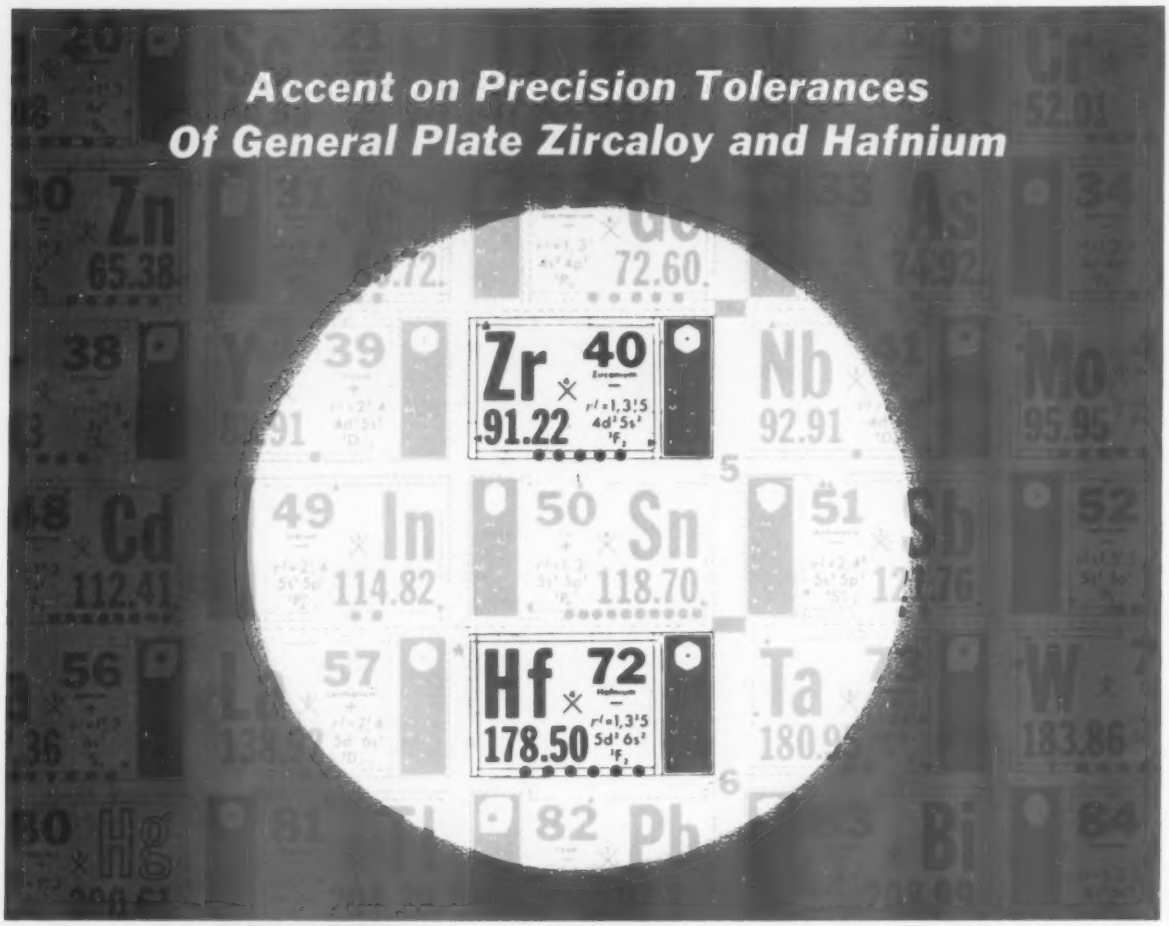

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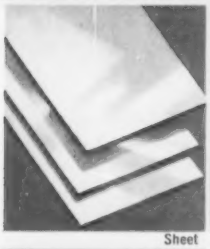
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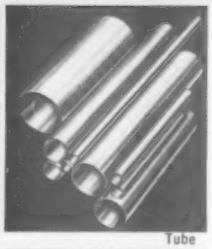
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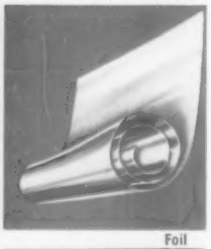
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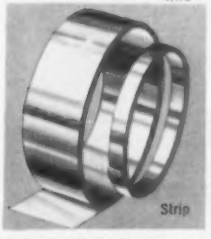
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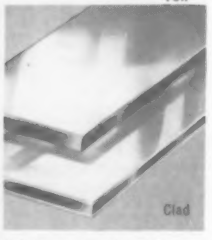
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About NUCLEONICS

Behind the Front Panel

Once a year in the spring, we devote our entire feature-article section to a special report on some subject of importance to the nuclear field. This June the special report (p. 63) is on Nucleonic Instrumentation. It's intended as a look beneath the surface (behind the front panel might be more apt) of several aspects of that important subject.

To help us decide exactly which aspects of nucleonic instrumentation to cover we polled a dozen or so specialists in the field. Far and away their first choice was for an article on the use of transistors. To write it we called on one of the world's leading experts in the subject, Fred Goulding of Chalk River, Canada. We hope you'll be as delighted as we were with his thoroughgoing coverage of the highlights of that subject. We say "highlights" advisedly because in a rapidly growing technology it is well-nigh impossible to provide definitive coverage. However, Goulding has included a very extensive bibliography and this should help the reader who would like to go more deeply into some facet of the subject.

Another major ingredient of the special report is Van Duuren's review of recent developments in halogen-quenched G-M counters. All too many people have been unaware of the quiet revolution that has been worked in the field of Geiger counters, in particular, with respect to the many novel geometries that are made possible by the development of "fat-anode" types. The chart on p. 87 shows you 11 designs at a glance. We hope it will complete your motivation to read the entire article.

More to Come

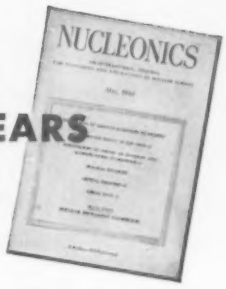
This special report on nucleonic instrumentation by no means exhausts our interest in the subject. Our Instrumentation and Measurements department, which is regularly devoted to that subject but is missing this month because of the special report, will be back in the July issue with a review of nuclear instrumentation developments in France by Marcel Surdin of the French AEC and a description of a new remote area monitoring system by Brown and Rogers of Tracerlab. On deck for later publication are such things as a review of latest advances in decay-time discrimination in scintillators by R. B. Owen of Harwell and a massive review of instrumentation developments at Savannah River by John Wilson.

Cleveland Reprise

Post mortem on the Cleveland Nuclear Congress, which we previewed in our April issue, can be found in the Nuclear Engineering (p. 96) and Applied Radiation (p. 114) departments where reports are provided on Project Plowshare and the A. D. Little study of radiation uses, respectively. As with any technical meeting, Cleveland will continue to influence our pages in the months ahead.

—*The Editors*

10 YEARS AGO



Analyzer tubes. Before pulse-height analyzer design settled out in favor of the types presently employed, considerable experimentation was carried out with special tubes designed to do the analyzing. An early tube of this type was built at the University of California Radiation Laboratory, Berkeley. Essentially it was a cathode ray tube from which the screen had been removed and replaced with an assembly of 48 "catcher" anodes ranged so as to intercept the beam, depending on its deflection. The deflection was in turn determined by the height of the incoming pulse to be measured. Pulse resolving time was limited to 35 μsec.—William E. Glenn, NUCLEONICS, June '49, p. 50.

Dean, Smyth to AEC. "The Senate has confirmed President Truman's nomination of Gordon Dean, professor of law at the Univ. of Southern California and Henry DeWolf Smyth, chairman of the department of physics at Princeton Univ., to fill two vacancies in the AEC." Thus reported the May, 1949 NUCLEONICS. Smyth served a full five year term and was succeeded by W. F. Libby; Dean, who had by then become Chairman of the Commission, was succeeded by Lewis L. Strauss in 1953.

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including a report on the
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The PRDC Case

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NUCLEAR REACTIONS

A Case of Stunted Growth?

DEAR SIR:

That the application of radiation as an industrial tool is becoming of increased interest to both government and industrial organizations goes without saying. However, as is often the case with a new technology, it is important that in its early growth nothing be done to stunt the growth pattern.

Unfortunately, I believe that such is the situation with regard to the AEC's position on radiation applications. In particular, I should like to direct myself to its position on massive-radiation applications.

The long-term goals established for the Office of Industrial Development, namely, to develop markets for isotopes, fission products and reactor energy, is commendable. Obviously, our infant reactor field would gain immeasurably if the waste products could be directed to practical uses. However, I believe that the method of achieving this goal bears careful scrutiny.

My contention is that in this field, as in all other economic areas, the law of supply and demand still holds. Consequently, the best and quickest way to achieve the long-range goal of the AEC is to help foster and develop the markets and requirements for many kilowatts of radiation energy. Further, I believe that, having developed requirements for megawatts of energy, the AEC can step down and let American industry and ingenuity determine the best and most economic means of satisfying these requirements.

Instead, the AEC, through its Industry Development Program, is trying to go the route of isotopes and reactors regardless of the practical economics today, tomorrow or even years from now. The end result, I believe, will be to the detriment of American industry and to the AEC's long-range goal.

If, as I feel will be the case, the programs now being sponsored by this agency result in ascertaining technical feasibility, but with the qualifying statement that the economics does not justify industrial application today because of high isotope costs, then many industrial engineers who might have been interested will shelve their projects awaiting the lower projected costs.

The end result will be to delay practical radiation applications and to shrink the potential demand for large quantities of radiant energy.

As a manufacturer of high-voltage accelerators, we naturally are concerned with this matter. Almost daily we have seen situations develop where radiation energy can play an immediate role if the cost is right. And for many applications, it can be proven that machine radiation is cheap enough today.

If the AEC wants to play a vital role in this field, let them support these practical programs and thereby develop immediate as well as future needs. But to offer support obliquely, prejudicing themselves in favor of isotopes and reactors, is to do a disservice to the radiation-application field. In addition, manufacturers like ourselves are put in a position of countering erroneous impressions regarding radiation costs that result from AEC emphasis on isotopes.

Further, since the AEC is a government agency, whose activities are financed by *all* the taxpayers, why should they choose an arbitrary position that defeats their long-range goal and at the same time unfairly fosters a government-supported competitor of accelerator manufacturers?

It is as if they ask us to help furnish the funds to bet on their horse in a horse race in which we have our own entry. Considering the lameness of their horse in today's race, the whole thing appears rather ludicrous.

—KENNARD H. MORGANSTERN,
President
Radiation Dynamics, Inc.
Westbury, New York

[EDITOR'S NOTE: A reply from Paul Aebersold, Director, AEC Office of Isotopes Development, solicited by NUCLEONICS follows.]

DEAR SIR:

We welcome the opportunity to respond to Dr. Morganstern.

Dr. Morganstern questions the approach being followed in the Commission's program for developing industrial applications of high intensity radiation. We consider this phase of the Isotopes Development Program to be relatively long range and believe that radiation energy offers promise as a processing tool, as diverse in its capability as temperature, pressure and catalysis.

The industrial radiation program is two-fold. First, it is aimed at developing technology for radiation processes through research and development at AEC national laboratories and through contracts with industry and research

organizations. Second, this program is aimed at developing radiation engineering parameters, such as utilization efficiency, dose distribution and safety, related to the utilization of quintalcurie and megacurie quantities of radioisotopes for radiation processes.

Dr. Morganstern is in agreement with the first aim, i.e., the development of "markets and requirements for many kilowatts of radiation energy." Any advances in this area will, of course, be of benefit to the total radiation industry including machine manufacturers.

It would appear that Dr. Morganstern is taking exception to the second programmatic goal, the development of large radioisotope sources equivalent to tens of kilowatts of machine power. Dr. Morganstern's point is that AEC attempts at developing engineering parameters of high intensity radiation sources should include machine technology.

In this regard, it should be observed:

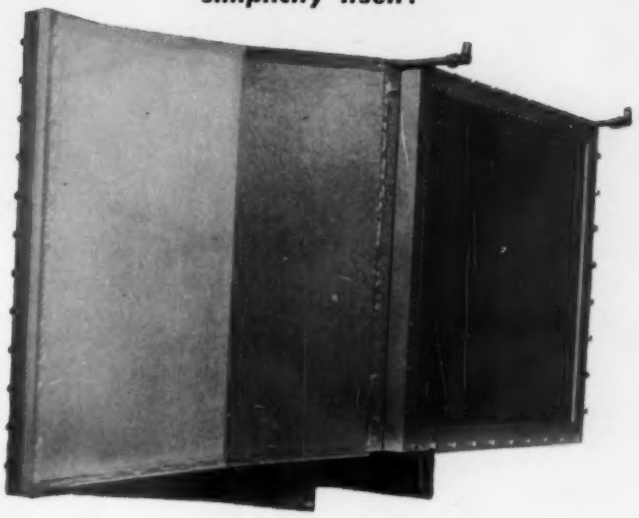
1. The high-voltage accelerator industry has developed to its present advanced state partly as a result of use of such accelerators in Commission programs in chemistry, physics, biology and medicine. This is a free competitive industry, although government or government contractors are major purchasers. In contrast, high-intensity radioisotope sources for radiation processing are in an early state of development, and AEC is the sole U. S. producer. The AEC has a broad responsibility to develop peaceful applications of atomic energy. It is the AEC purpose to bring the technology of high-intensity radiation applications up to a level that will permit the establishment of a free-enterprise radiation production and utilization economy.

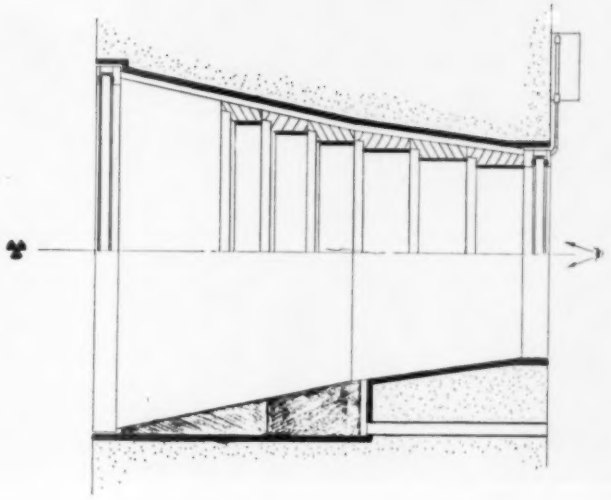
2. Contrary to the implications of Dr. Morganstern's letter, high-intensity radioisotope sources are not competitors of machines per se. For some particular processes, it doubtless will prove true that only machines should be considered; in other instances high-intensity beta and gamma sources will be preferred for technical reasons such as depth of penetration, uniformity of treatment, more efficient source geometry and absence of induced activity.

3. The economic situation is not as clear-cut as Dr. Morganstern implies. Only hypothetical economic analyses exist comparing costs of radioisotope sources and machines. These com-

(*Cont. on p. 143*)

simplicity itself!





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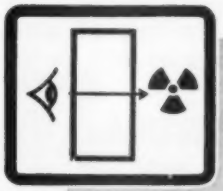
Easy to buy, easy to install. The Penberthy double-taper window is simply pulled into place from its shipping pallet. Both hotside and coldside varieties are available—no grouting or shotfill is required in either case.

Lead glasses by Penberthy start clear and stay clear. Whether airsealed or oilsealed, these windows do not fog and do not leak.

Penberthy windows—about two thousand of them—have been in use since 1949, in many countries and climates—from one inch to six feet thick—from 10 pounds to 18,000 pounds—in densities from 2.5 to 6.2.



Originators of heavy lead glass

PENBERTHY INSTRUMENT CO.

4301 6TH AVE. SOUTH • SEATTLE 8, WASH.

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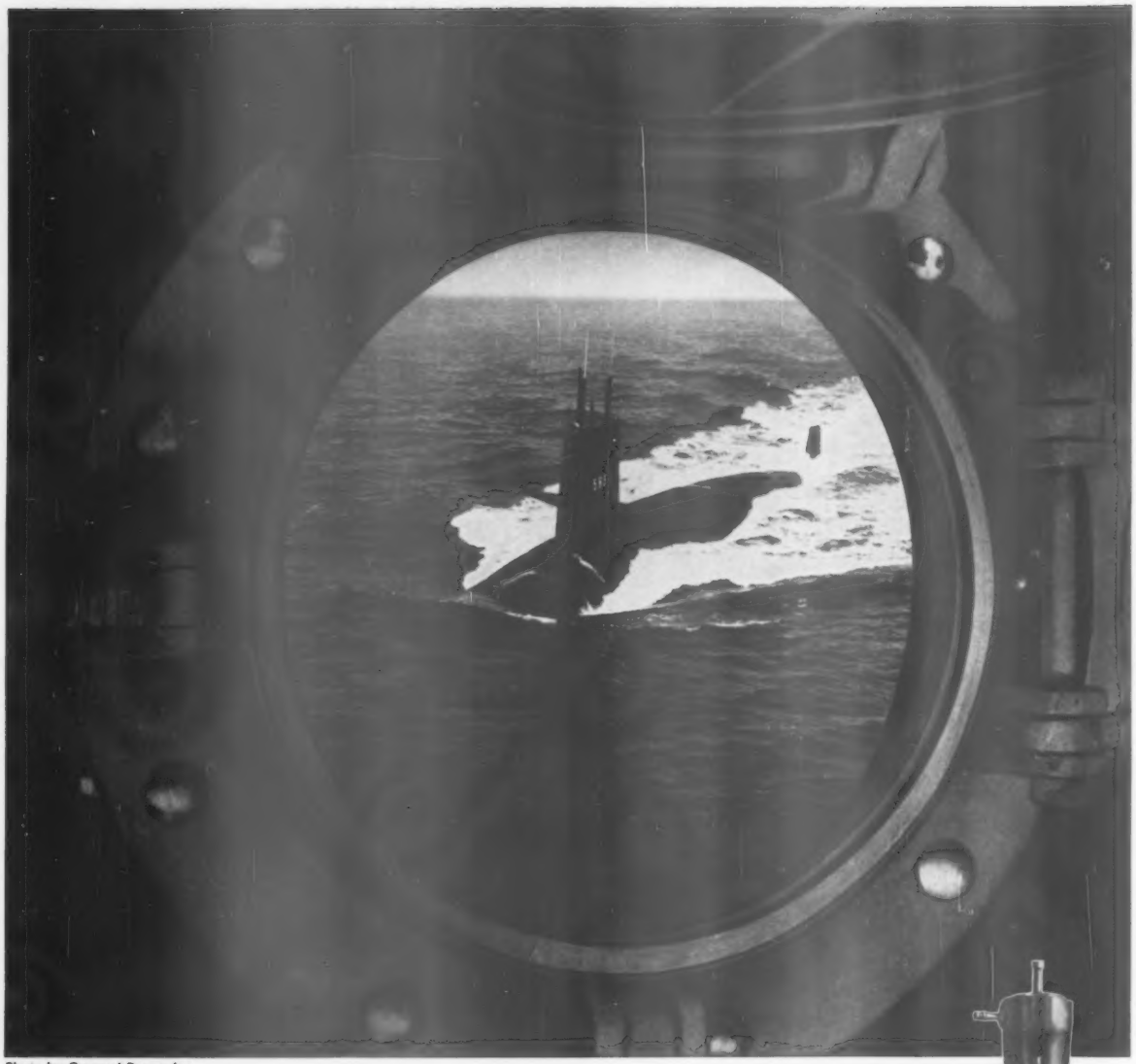


Photo by General Dynamics

IN THE NAVY'S NEW NUCLEAR FLEET

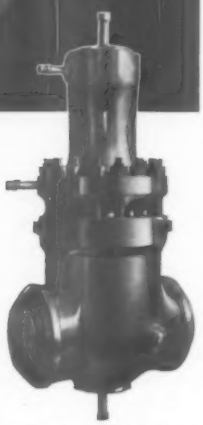
Darling Stainless Steel Valves are "on duty"

Meeting the Navy's rigid specifications for valves in nuclear power plants demands the highest quality and production standards.

Darling is one of the select group of manufacturers supplying stainless steel valves for the Navy's new nuclear submarines. Darling valves are "on duty" on the Skipjack, as well as other nuclear subs still unnamed. These valves incorporate the *exclusive revolving double disc parallel seat* feature... which insures positive sealing and ease of operation.

This Navy acceptance of Darling quality standards holds important implications for designers and builders of commercial atomic power plants. Our know-how and precision manufacturing facilities are at your disposal.

Write us for information, or we'll gladly arrange for a Darling sales engineer to call.



Darling 14" stainless steel gate valve of the type used on the Skipjack.

DARLING VALVE & MANUFACTURING CO.

Williamsport 6, Pa.

Manufactured in Canada by Sandilands Valve Manufacturing Co., Ltd., Galt 19, Ont.

DARLING VALVES

8 PROVEN INSTRUMENTS

to measure and control micro-currents

linear micro-microammeters

MODEL 410 offers maximum sensitivity and fast response for general applications. Typical are measurement of currents in ion chambers, photo cells, vacuum tube grids, and back currents of silicon transistors. No switching transients created by switching from range to range. Features tabulated below, with similar Model 411.

log n and period amplifiers

MODEL 420 provides superb stability for dual monitoring of power level and reactor period. It measures positive or negative reactor period from −30 to ∞ to + three seconds and has five-second recovery from overloads. Accuracy is within 3% at center scale. Log N current ranges shown below.

contact-meter micro-microammeters

MODEL 411-C has a meter-relay with adjustable contacts, providing economical control or alarm circuitry. Five-ampere contacts are brought out through an AN connector. All other Keithley Micro-microammeters and Log N Amplifiers also are available with contact meters for specific applications.

logarithmic micro-microammeters

MODEL 412 features a large single scale covering six decades with no range switching. Typical uses include reactor control, radiation monitoring and materials testing. Accuracy is within 0.2 decade; zero drift within 0.5 decade in eight hours. Features shown below, including similar Model 413.

MODEL	FULL SCALE RANGES	OUTSTANDING FEATURES	PRICE
410	10^{-3} to 3 x 10^{-13} amp.	Twenty ranges; fast response; maximum sensitivity	$ 490.00
410-C	10^{-3} to 3 x 10^{-13} amp.	Same as 410 except contact meter replaces panel meter	$ 625.00
411	10^{-3} to 10^{-11} amp.	Seventeen ranges; fast response; excellent zero stability	$ 535.00
411-C	10^{-3} to 10^{-11} amp.	Same as 411 except contact meter replaces panel meter	$ 670.00
412	10^{-13} to 10^{-7} amp.	Single range; high stability log N meter; fast response	$ 485.00
413	10^{-11} to 10^{-5} amp.	Same as 412 except measures larger currents	$ 485.00
420	10^{-13} to 10^{-6} amp.	Single range; adjustable response speed; superb stability	$ 950.00
420-C	−30 to ∞ to + 3 sec.	Same as 420 except two contact meters replace panel meters	$1220.00

WRITE TODAY *for detailed data on these and other Keithley Instruments for nuclear and research applications.*

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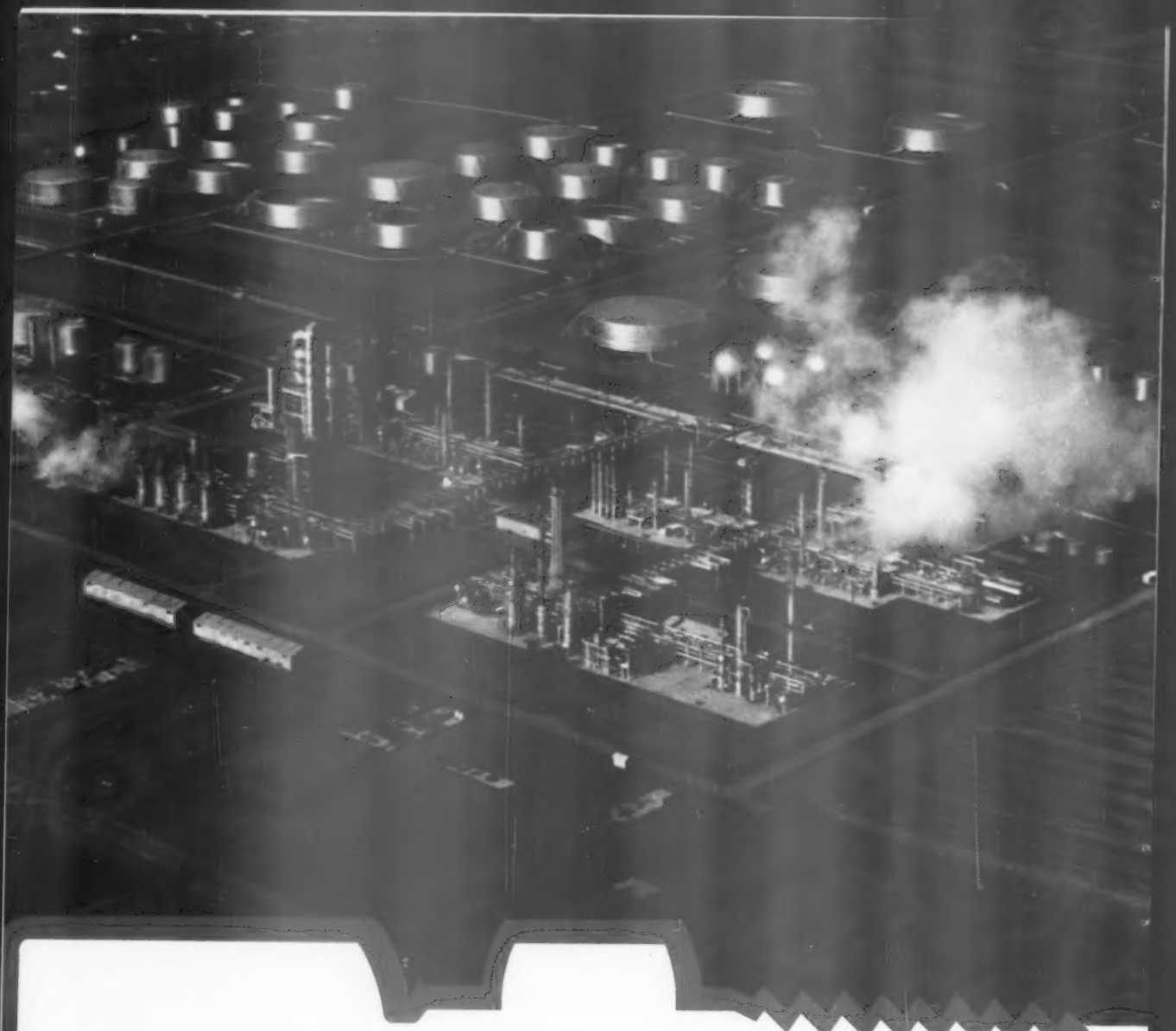


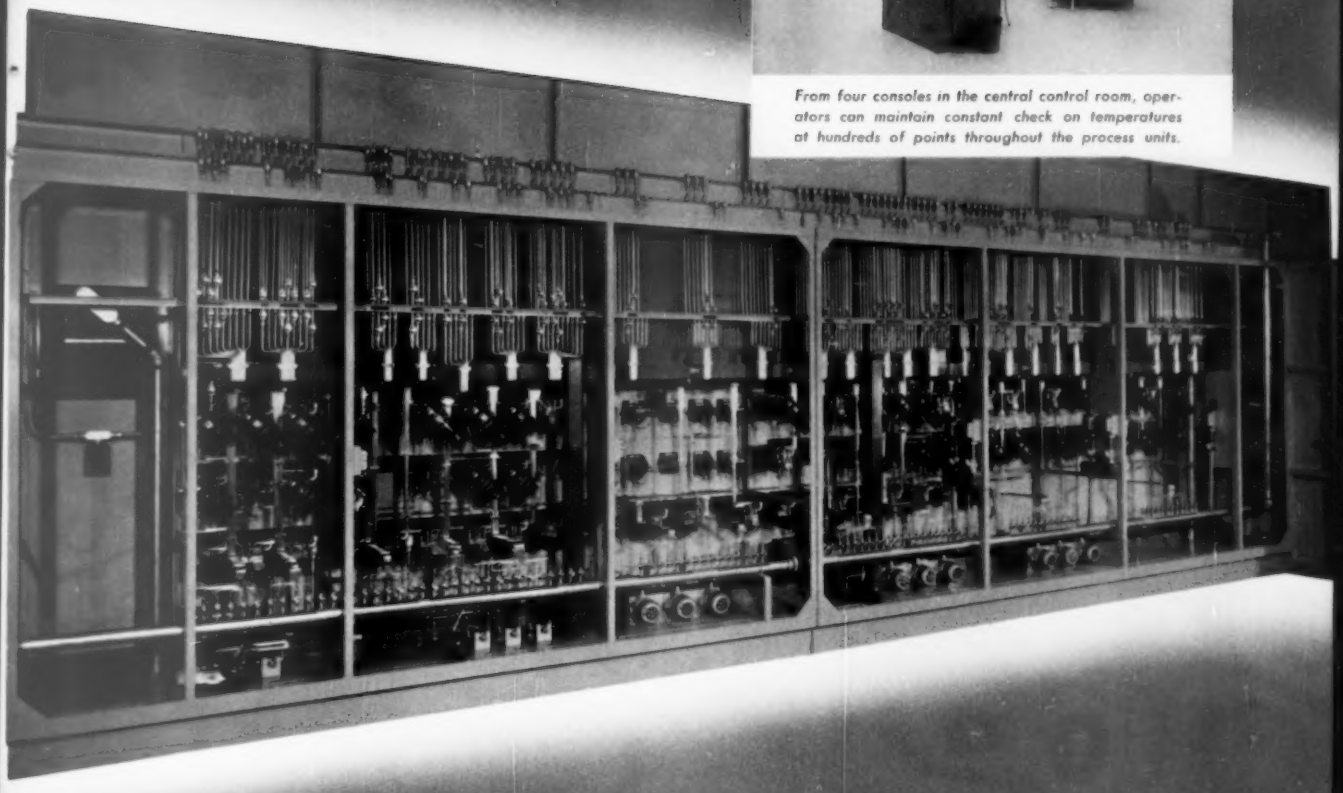
NO COMPROMISE WITH QUALITY IN THIS MODERN PETROLEUM PLANT

The capacity of this new Texaco Refinery at Anacortes, Washington, is 45,000 barrels of crude oil per day, processed into a full range of finished Texaco quality products . . . high octane and regular gasoline, jet fuel, burner oil, kerosene, diesel oil, bunker fuel and propane gas.

Quality control is the watchword here . . . with automation and instrumentation bearing the major responsibility. More than 30,000 Swagelok Tube Fittings were used for instrumentation and steam tracer lines throughout the plant, including over 12,000 for the panel boards in the control center. In keeping with their high standards of quality in panelboard manufacturing, Swanson Engineering & Manufacturing Co. selected Swagelok Tube Fittings to secure precision control with torque-free seals that are absolutely tight. In the science of sealing, Swagelok Tube Fittings approach the ultimate desired by designers today.

CREDITS: *Owner: Texas Company. Complete engineering procurement and construction: Bechtel Corporation, San Francisco, Calif. Panel Boards for Central Control Room manufactured by Swanson Engineering & Manufacturing Co., Inglewood, Calif.*

From four consoles in the central control room, operators can maintain constant check on temperatures at hundreds of points throughout the process units.



This view of back of panel board illustrates the outstanding craftsmanship in design and construction by SWANSON ENGINEERING & MANUFACTURING CO.

In this great new Texaco Refinery Swagelok Tube Fittings stand guard against pressure, vibration and torque

In the refining of 45,000 barrels of crude per day at the new Texaco Refinery, obviously all of the units in the process control line must bear a big load of trust in performance.

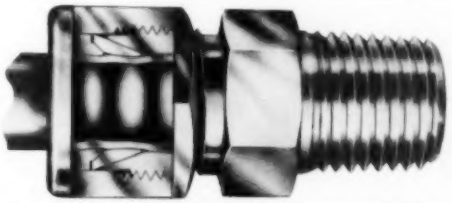
The Swagelok Tube Fittings used in the plant and control panels represent 30,000 trusts in dependable performance. Their design is unique, based on the principle that

nothing is quite so good as the finest that man's ingenuity can create and that precision machines can produce!

The new Texaco Refinery at Anacortes, Washington, is one of many different industries using Swagelok Tube Fittings for trouble-free, leak-proof operation.

Crawford Fitting Company
884 East 140th St., Cleveland 10, Ohio
Crawford Fittings (Canada) Ltd., Niagara Falls, Ontario, Canada

Swagelok®



Swagelok Tube Fittings are available in any machinable metal or plastic, in sizes for 1/16" through 1" O.D. tubing.

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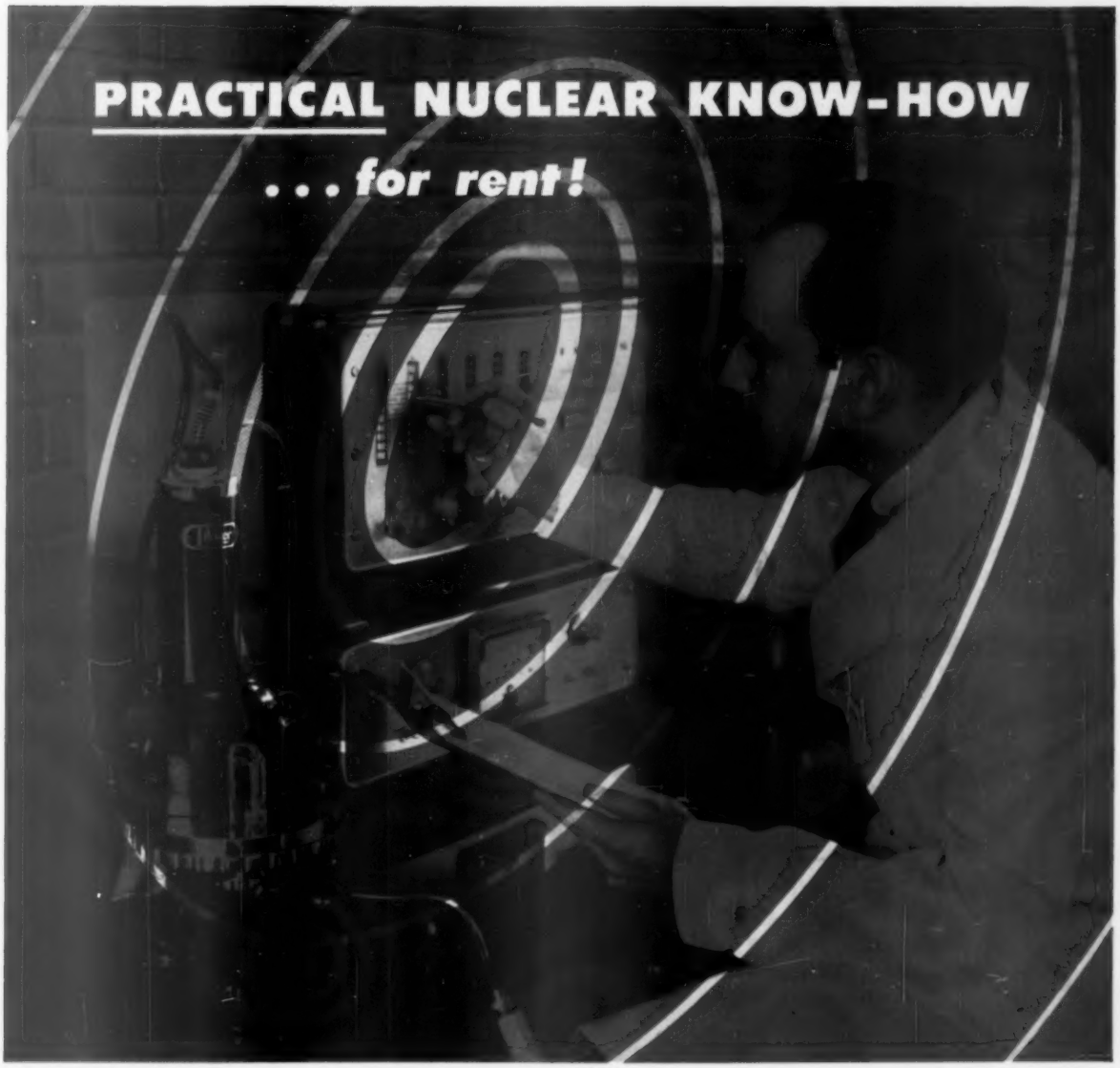
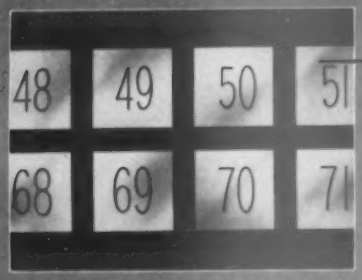
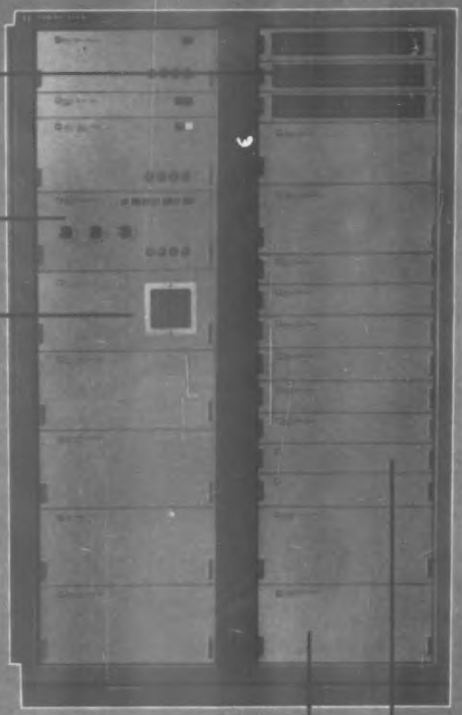
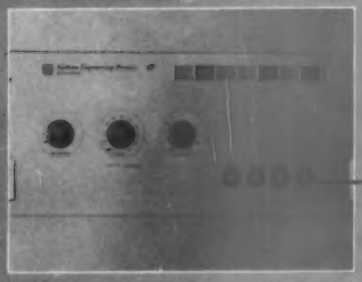


New packaged



THREE 40-POINT ANNUNCIATORS make it easy for the operator to tell at a glance which variables are off-normal.





DIGITAL VISUAL DISPLAY and variable selector switches make it easy to select any single variable and watch all trends and changes continuously.

SERVICING IS SIMPLIFIED by an indicator-light panel showing the completion of each step in the analog to digital conversion. The sequence programmer can be changed from automatic to hand advance to permit operator to check each step.

UNIQUE INPUT SELECTOR is unusually dependable because of its sealed, oil-immersed construction. Servicing is normally limited to visual inspection every 6 months. Drawers pull out so voltage checks can be performed without shutting down system.

PINBOARD PROGRAMMING adds flexibility. You can change the logging or scanning sequence at will . . . substitute one type of input for another. Range, span, and zero adjustment are set by inserting pins in their proper places. No calculations are required. The pinboards are pinned in familiar units of measurements.

Honeywell logger-scanner

...accurate within ± 0.1% of reading

...pinboard programming for maximum flexibility

Here's a standard, all-purpose 120-point logger-scanner system with features formerly found only in more expensive, custom-designed equipment . . . the first of several packaged logger-scanners being introduced by Honeywell. It offers the ultimate in accuracy, flexibility, dependability and simplicity of maintenance. Wide ambient temperature operating limits—60 to 120°F—eliminate the need for special air conditioning equipment.

The Series 3120 accepts signals from primary measuring instruments—thermocouples, flow, pressure or other transducers. It measures these signals, digitizes them, and prints their values in immediately usable form. A thermocouple reference oven can be supplied to accommodate three types of thermocouple inputs—types T, J, and K—which are automatically linearized over their entire range to within 0.1% accuracy.

The operator can select either automatically or manually initiated logging cycles. He can set the system to log all variables automatically at preset intervals, or manually energize the system to operate on demand, between logging cycles.

Between logging cycles, the system can scan off-normal alarm points—high, low or both—at a rate of 7 points per second. Upon detecting an off-normal point, the system sounds an alarm, lights a point-identification light, and prints the time, point number and off-normal value on adding machine tape. During log cycles, off-normal points are printed in red on the log sheet.

Get complete details from your nearby Honeywell field engineer. Call him today . . . he's as near as your phone. MINNEAPOLIS-HONEYWELL, Wayne and Windrim Avenues, Philadelphia 44, Pa.

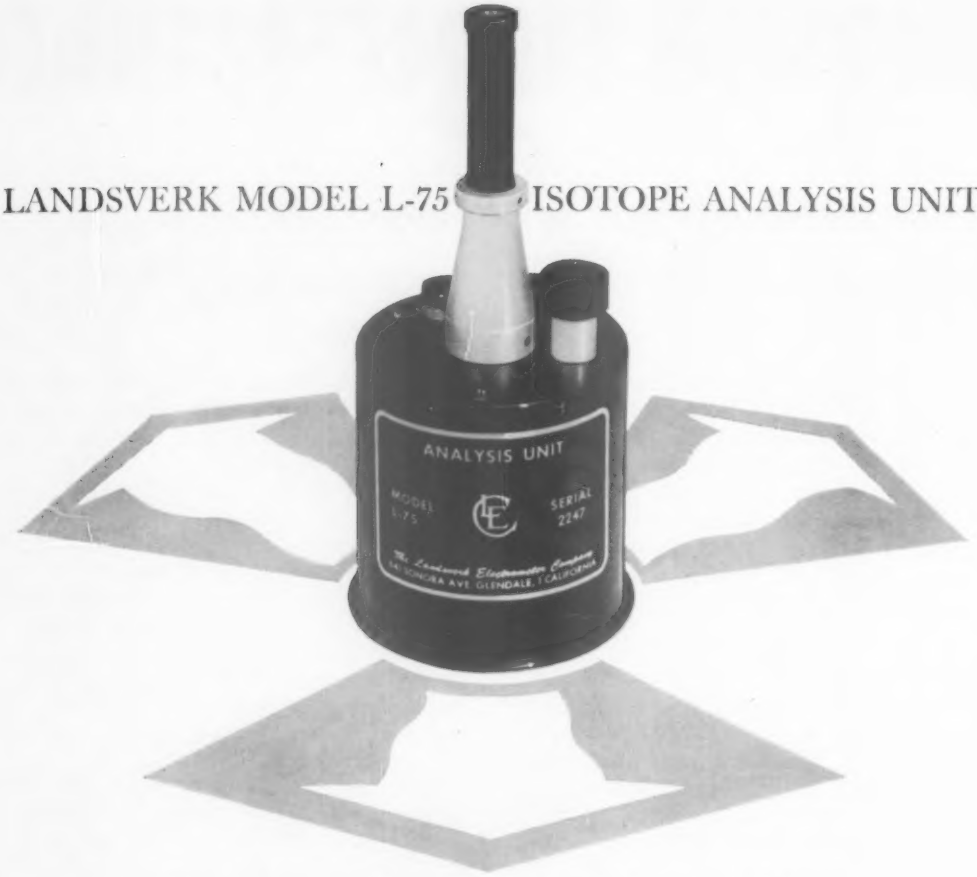
Honeywell

First in Control

TWO TYPEWRITERS permit a single line log allowing columnar comparisons. Separate alarm printer records all off-normal variables.

STANDARD MODULAR COMPONENTS are assembled on chassis mounted as individual drawers in relay racks. All drawers are connected by plugs for easy servicing.

LANDSVERK MODEL L-75 ISOTOPE ANALYSIS UNIT



One measurement is worth one hundred expert opinions

The Isotope Analysis Unit is a sensitive, accurate ionization chamber instrument for measurement of alpha, beta or gamma radiation. It features simple, reliable operation and low maintenance cost. Widely accepted by A.E.C. laboratories, it is also used extensively in the A.E.C. teacher training program.

Model L-75K is the kit form which includes sample trays, planchets, filters, light source, special holders.

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ASCO SOLENOID VALVES FOR

COMMERCIAL VESSELS | SUBMARINES | POWER PLANTS | SURFACE VESSELS

Pioneering design, development and production work has brought about a "first generation" of solenoid valves for use in the primary systems of water cooled nuclear reactors.

From ASCO experience, ASCO facilities, and ASCO design imagination now come a variety of proven solenoid valves to control the flow of water in the primary and secondary systems of reactors in submarines, surface vessels and industrial power plants. Available in many sizes and designs, these stainless steel packless type (hermetically sealed) valves are distinguished by the highest standards of reliability, exceptionally tight seating and have been exposed to the most rigid tests simulating actual working conditions.

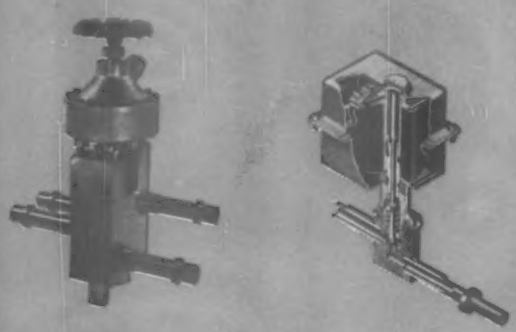
Beyond the "standard" units shown which are already on the job in various reactors, ASCO research and development is already involved in radically new designs which will be required in other types of power reactors, including boiling water, gas cooled, and liquid metal. ASCO nuclear engineering teams are doing their pioneering work backed by the most advanced nuclear research facilities in solenoid valve manufacturing.

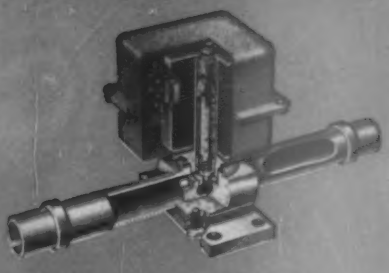
In design — development — production — ASCO single source responsibility is a warranty of performance and quality.

Precision Craftsmanship . . . is evidenced by this ASCO machinist's painstaking care . . . and in the precision products engineered and manufactured by the Automatic Switch Co.

Modern machinery and production facilities, coupled with old fashioned pride in workmanship are behind the quality line of ASCO Solenoid Valves.

A few typical Solenoid Valves supplied for the primary system are illustrated here





STOP VALVE — For Coolant Purification System — shuts off circulating flow when temperature exceeds a predetermined value. Suitable for pressures to 2500 P.S.I. at 550° F, the valve will open against 125 P.S.I. differential pressure — others are available to open against 2500 P.S.I. differential pressures. Normally closed (valve fails closed). Supplied in 1" size, all stainless steel construction with stellite seats and discs.

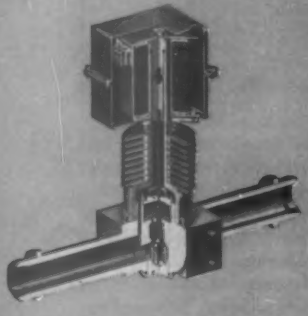
PRESSURE OPERATED 4 WAY VALVE — Controls main cylinder operated Stop Valve in Circulating Loop. Valve is pressure operated requiring a separate source of air of 400 P.S.I. Equipped with manual operating handle and position indicator, valve has beveled, poppet type seats and discs for exceptionally tight seating. It is suitable for handling water at 3000 P.S.I. and 550° F. Has all stainless steel construction and stellite trim.

BY-PASS COOLANT VALVE — Designed to control the flow of water in the Emergency Cooling System. This valve is of the normally open type (valve fails open). Engineered for low differential pressures, this by-pass coolant valve is suitable for system pressures up to 2500 p.s.i. at 670°F. It is supplied in 1" size, features all stainless steel construction and stellite trim.

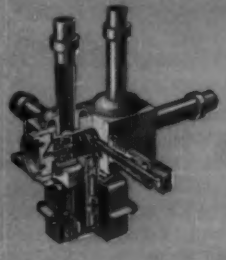
NUCLEAR REACTORS

ASCO is the only solenoid valve manufacturer with its own HOT TEST LOOP. Here, valves for atomic energy applications are subjected to rigid tests, simulating actual working conditions.

Modern Laboratory, Research, Testing and Production Facilities help keep ASCO abreast of atomic power requirements for automatic control.



RELIEF VALVE—For water and steam — valve is electrically operated, controlled by pressure sensing device to relieve excess pressure. Normally closed (valve fails closed). Suitable for pressures to 2500 P.S.I. at 700° F. Available in 2" and 3" sizes. Body materials are monel, stainless steel and carbon steel with stellite seats and discs.



4 WAY VALVE—Controls main cylinder operated Stop Valve in Circulating Loop. Valve is solenoid pilot controlled and has beveled, poppet type seats and discs — for exceptionally tight seating. Supplied with manual override. It is suitable for 2500 P.S.I. differential pressure at 600° F. Supplied in 1" size, all stainless steel construction and stellite seats and discs.

TYPICAL ASCO SOLENOID VALVES SUPPLIED FOR SECONDARY SYSTEMS

2 WAY VALVES
Remote control pilot valve for controlling air system in air propulsion control panel. Normally closed, has forged brass body, Navy approved high shock solenoid and silbraze union connections.

MANUAL RESET 2 WAY VALVES
For safety shut-off to high pressure drain system and steam condenser. Of the no voltage release type, it has Navy approved high shock solenoid and movement, silbraze union connections and stainless steel seats and discs.

STANDARD ASCO VALVES FOR NUCLEAR INSTRUMENTATION CONTROL, AND OTHER GENERAL PURPOSE APPLICATIONS

2 WAY VALVES
From ⅛" to 6" pipe sizes, temperatures to 600° F, pressures to 1500 P.S.I.

3 WAY VALVES
From ½" to 6" pipe sizes, temperatures to 450° F, pressures to 1000 P.S.I.

Proposals submitted upon receipt of specifications. For complete information, write for Nuclear Reactor Valve Brochure V5055 and complete Solenoid Valve Catalog #25.

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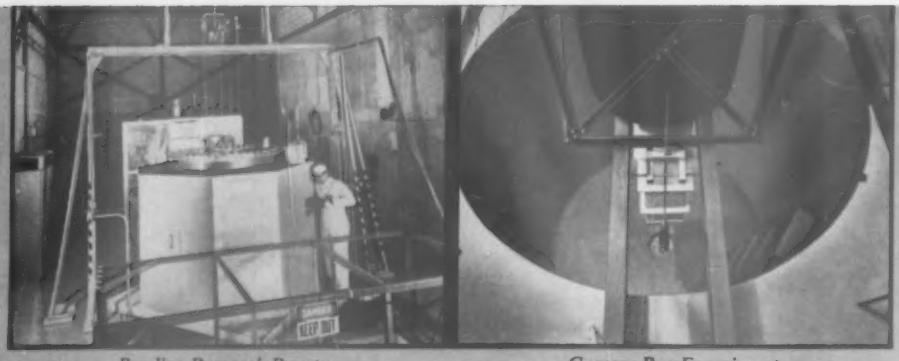
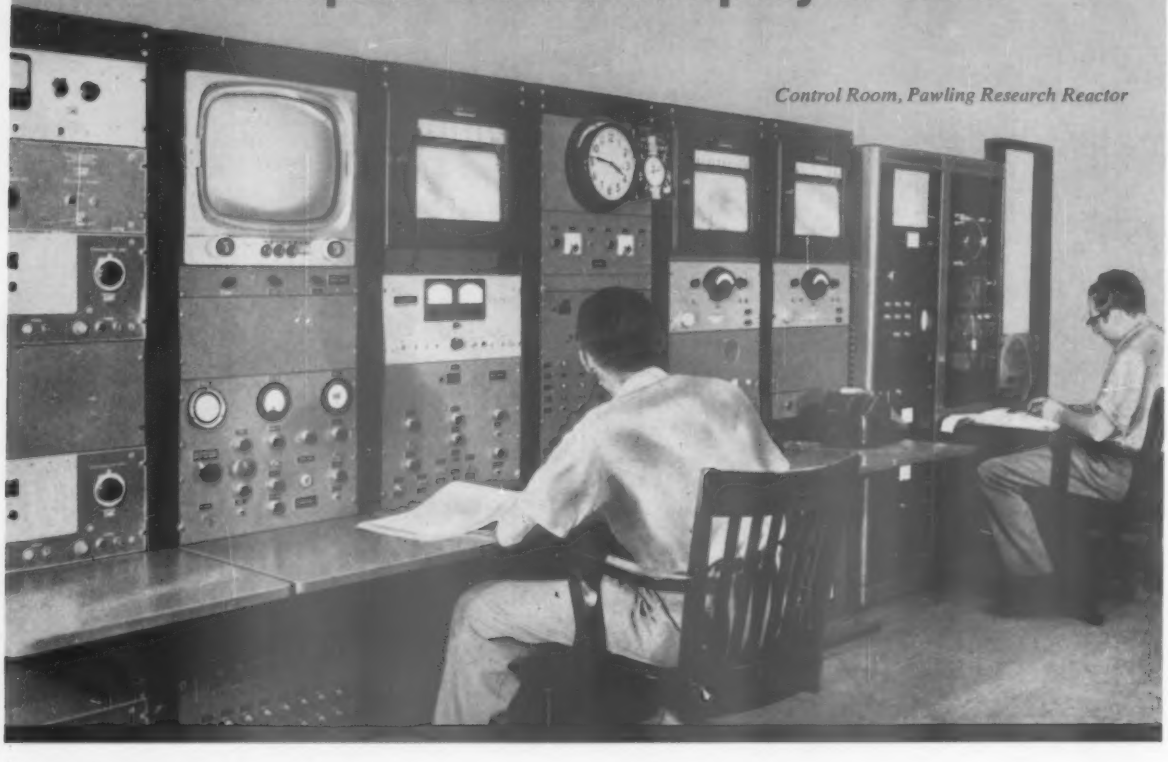


Pawling Research Reactor

Gamma Ray Experiment

a complete reactor company at work



Control Room, Pawling Research Reactor

A reactor company's ability to gain the best solution with a given set of design parameters is proportional to the quality of its experimental physicists. This is why NDA maintains an experimental physics group that has gained a wide reputation for quality and productivity.

This group's working tools include the Pawling Research Reactor and critical facility, a major mathematics center with Datatron Computer and a hot lab (10,000-curie capacity) for chemical confirmation of the experimentalist's work. In addition to use of its own facilities, NDA has carried out programs based on the high neutron fluxes available at the National Reactor Testing Station in Idaho.

NDA's experimental physics group conducts complete reactor core and shielding physics programs. It also addresses itself to specific problems such as exponential and single cell experiments, reactivity value studies and related projects to which the experimental physicist brings unique insights and skills.

Working for itself and others, NDA participates in reactor development on a broad front. As a result, it offers unusual opportunities for experimental physicists and other reactor scientists and engineers to grow with the company and the industry. Write for employment information.

a complete reactor company

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ROUNDUP of Key Developments in Nucleonics

McCone Begins 2nd Year with Strong Hand on Tiller

AEC Chairman John A. McCone, according to a story current in Washington, had a difficult time one day recently convincing Democratic members of the Joint Committee on Atomic Energy that AEC would push construction of a particular project as it had promised.

"May I have a pin, Mr. Chairman," he asked.

"What for?"

"So I can prick my finger and give you my word in blood." And the Democrats gave him no more trouble.

The story is characteristic of the tough but flexible man who next month will round out his first year in the AEC's top job.

How is the McCone Commission operating? How does it differ from the establishment as run by Lewis L. Strauss? One member of the Strauss Commission leaves at the end of this month—Willard F. Libby—and another's term expires on the same day—John S. Graham; is a "new" Commission in prospect?

NUCLEONICS *put five questions on AEC's reactor and radiation program policies to Chairman McCone. His answers are on page 22.*

Taking the last question first, it appears that Libby is the only member of the Commission to depart in the foreseeable future—Graham, apparently, will stay. Further, the staff reshuffling which has taken place since McCone came on the job—from a new general manager down through a new regime in the Reactor Development div. (NU, Nov. '58, 22; July '58, 21)—has given the Commission a "McCone" staff which is not likely to change soon. Also, there is current discussion within the Commission to channel the work of the national laboratories away from development work and toward research alone (JCAE is considering hearings on the labs' future within the next few weeks).

Commissioners Themselves

Libby, the only scientific member of the Commission, is stepping down two years before the expiration of his term to return to research work at the University of California, Los Angeles. His successor had not been named in late May. Warren Johnson, chairman of AEC's General Advisory Committee and dean of physical sciences at the University of Chicago, was reported to have been offered the job.

Graham, the only Democrat on the Commission, has not disclosed his plans. But it is widely expected that he will be offered reappointment and will accept.

Rumors earlier this year that Harold S. Vance would resign this fall have faded and Congressional Republicans have been assured that he will stay on.

John Floberg, a political independent and one of the most vigorous members of the Commission, has three years of his term remaining.

McCone's Leadership

No one, in or out of the Commission, harbors any doubts that the dominant figure is McCone himself. Partly this is a natural result of the prestige and power that goes with being chairman. But the man's own personal drive is a big factor, too.

Long before he joined AEC, McCone had won a reputation as a no-nonsense man who makes exacting demands on his staff. He has lived up to this reputation at AEC, where urgent memos from the chairman are called "McCone-O-Grams."

There are occasional staff grumbles that the present Commission does not give the same weight to staff recommendations as in the past—that the commissioners are increasingly inclined to make technical decisions on their own. But one industry representative in Washington gives the other side:

"Admiral Strauss and McCone are both businessmen and champions of private enterprise. But McCone has one advantage—he has a technical background. So when a staff man or an industry man comes in with high-flown talk about the expected performance of a proposed reactor, McCone says 'Give me your breakdown.' And if the backup material isn't sufficient, then you just have to work until it is.

"This is the first time some of these people have really had to justify everything."

Graham—Chief Dissenter

Commission decisions are made by majority vote, with the views of each member recorded. But in practice, there are few dissents on

JCAE subgroup okays 9-reactor program for '60

Pretty much as expected (NU, May '59, 25), an AEC construction program calling for a start in fiscal '60 on nine commercial reactors, three or more reactor-design studies and a natural-circulation, boiling-water prototype for the naval reactor program (NU, Apr. '59, 21), was approved last month by a subcommittee of the Joint Committee on Atomic Energy. The full committee was expected to approve the program—with the possible addition of a capital-subsidy scheme—by end-May or early June. Capital subsidy, if okayed, would probably cover something less than 100% of excess construction cost of a nuclear power station over a conventional station. Highlights of the subcommittee-approved program:

- Authorizes both the Oak Ridge and Philadelphia Electric gas-cooled reactors but requires reimbursement of AEC aid if the latter is not built.
- Authorizes AEC aid for a 50–100-Mw(e) high-power-density BWR (General Electric and Consumers Power of Michigan are dickering on such a plant), plus an intermediate-sized reactor AEC is free to designate.
- Authorizes two small reactors under the second round of the Power Demonstration Program—AEC-owned, but operated by public power.
- Authorizes AEC to build (1) organic-moderated reactor experiment No. 2; and (2) a process-heat reactor.
- Authorizes an AEC or cooperative project for nuclear superheat in a boiling-water reactor.
- Authorizes $5.5-million for reactor-design studies: heavy-water; a nuclear-tanker reactor; a small reactor for remote military power.

major issues. Usual procedure is informal discussion among the five to hammer out an acceptable solution before a formal vote.

However, despite criticism of Graham as an insufficiently vigorous advocate of "Democratic" programs, this quiet North Carolinian is generally considered the chief dissenter. It is also understood that McCone gives considerable weight to Graham's views as part of a continuing effort to keep peace with JCAE Democrats.

During the Strauss regime, Graham publicly disagreed with the Commission decision on the arrangement with Pennsylvania Power and Light (NU, March '58, 28)—a project which was later abandoned by the sponsors themselves.

More recently, Graham refused to go along with approval of proposed aid to the Philadelphia Electric group's advanced gas-reactor project (NU, Dec. '58, 17) unless certain changes were made in the contract. He was outvoted. But the changes were made and final approval was unanimous.

McCone

McCone and Congress

When McCone took over the AEC chairmanship, he set one overriding goal: to get along with key Congressional Democrats and, thereby, avoid the pitfalls suffered by his predecessor. He assiduously wooed Sen. Clinton Anderson (D–N. M.), JCAE chairman, and went out of his way to satisfy the Democrats on such questions as ground rules for the Reactor Demonstration Program and construction of both the convertible plutonium-production reactor at Hanford, Wash., and the gas-cooled reactor designed by Kaiser and ACF Industries.

The resulting "honeymoon" appeared to be shattered when McCone lost his temper at a JCAE hearing and accused Rep. Chet Holifield (D–Calif.) of releasing a critical press release before McCone had finished his testimony (NU, Apr. '59, 17).

It was then that McCone did something which Strauss always found difficult to do—he apologized for the "misunderstanding." There will be many opportunities for such misunderstandings in the future but at this writing, McCone is on cordial terms with a majority of the Democratic-led JCAE.

McCone Defines AEC Policies on Reactors, Radiation

NUCLEONICS *last month put five questions to AEC Chairman John A. McCone. Here are his answers.*

1. AEC, under your chairmanship, has moved away from the argument that full-scale power reactors must be built to demonstrate construction and operation economics of nuclear power. Instead, it is now contended that only small reactors capable of upsizing without major design change should be built. What is the reasoning behind this "new approach" to economic nuclear power?

It is true that the civilian power reactor program which AEC has presented to Congress [NU, March '59, 17, 28] emphasizes the construction of prototype rather than full-scale central station plants at this time. (By a prototype plant we mean one intermediate in size between experimental and full-scale plants but sufficiently large and complete so that it will provide a sound basis for extrapolating to the operation, economics and efficiency of a full-scale plant.) We have emphasized prototypes because, along with others who have surveyed this field recently, we believe they are a superior device for achieving the objectives of the program within the time specified. They can be built in less time than full-scale plants. They are far less costly. It is more practical to build flexibility into them, to make changes in them after they are built and to emphasize fact finding, as opposed to power production, in their operation.

The size of the prototype reactor will vary, depending on the particular design and on the essential features which must be demonstrated. The intent is to obtain necessary information in minimum time, at minimum cost.

Emphasis on prototype reactors does not mean that the Commission has no interest in plants of larger size. If a large-scale plant is proposed which would seem to contribute in an important way to the program's objectives, it would be eligible to receive research-and-development assistance and waiver of [fuel] use-charges, within available authorization and funds, under the "unsolicited proposals" part of our program as proposed to the Joint Committee on Atomic Energy. Generally speaking we expect that large-scale plants will be built under normal industry initiative at such time as utilities can expect that they will prove to be economic, or nearly economic, over their service lifetimes.

2. Does the "new approach" reflect a Commission feeling that the U. S. can and should depend on the 1-million-kw Euraton arrangement for large-reactor experience, while the domestic program is scaled down in terms of reactor sizes and costs?

We believe that the Commission's domestic program is by itself adequate to achieve the objectives established for it. Without question much will be learned from plants built for Euratom, but the prospect that such plants would be built was not a determining factor in the formulation of the domestic program.

3. For something like two years many of the reactor industry's spokesmen, including those of the Edison Electric Institute, have urged the government to state long-range goals for the U. S. program and to state the federal policies (such as your proposed capital-grant program) under which the goals might be achieved. This would also include some statement of total effort over the period until the goals were achieved, as well as the spelling out of steps AEC might take to "accelerate" reactor devlopment. (a) Is the program you presented to Congress in February intended as AEC's answer to the industry's urging for an accelerated, long-range program? (b) If not, is AEC planning to go beyond the capital-subsidy proposal, for example, to accelerate development? (c) Is the federal budgetary situation such that AEC could go beyond the February program if it were inclined to do so—either on its own or jointly with JCAE?

This item really contains three questions which I will answer in turn:

(*a*) The program which AEC presented to Congress in February is intended to provide the objectives and the framework for our long-range nuclear power program. At the same time, our specific proposals were submitted for fiscal '60. This '60 program was but the first step in the implementation of our long-range goals and will be followed by additional proposals in subsequent years. The viewpoint of industry was solicited by the AEC and their suggestions concerning a long-range program were carefully considered by the Commission before this program was submitted.

(*b*) We believe that the program has built into it all of the assurances which are needed to move it forward at the desired speed. Through the capital-grant feature we hope to obtain the very real practical benefits of utility participation in the program and to facilitate the ultimate transition of the utility industry to nuclear power. But even if acceptable industry responses are not received to invitations involving offer of capital grants, the program will go forward through the alternative arrangements involving government construction.

(*c*) Certainly it should be clear that the AEC operates within an institutional framework which involved submission of an Executive budget, authorization of major projects by JCAE, appropriation of funds by the Congress, and apportionment of funds by the Bureau of the Budget. If circumstances appear to require that the civilian power program be enlarged, there are means available within this framework for accomplishing this. At the moment, however, we regard the program as presented to be sufficient for achieving the nation's objectives in this field.

4. Has the reactor industry given you any indication that it will step up reactor programming as a result of the capital-grant availability? What kind of impact do you expect the subsidy to have if it is approved by Congress?

Discussions over the past year led to the conclusion that the participation of industry in nuclear-power development might be increased if assistance were offered beyond that available through the Power Demonstration Reactor Program. The capital grant appeared to be a logical form of increased assistance. In particular, we felt that, coupled with a provision that reactor types would be selected by the Commission, it would lead to minimum distortion of nuclear-power technology.

Referring to the specific wording of your question, asking whether industry would "step up reactor programming as a result of the capital-grant availability," it is necessary to point out that the "programming" of reactors eligible for the capital grant would be determined by the Commission. That is, the Commission would specify the type, approximate size, schedule, and conceptual design of the plants involved. We believe, however, that the availability of the capital grant for these selected projects would give greater assurance that the projects would proceed under cooperative arrangements with industry.

The "impact" of capital grants and the program proposed for administration of these grants is expected to be reflected in two ways: (1) closer collaboration between industry and the AEC in the evaluation of reactor concepts in light of current technology, and (2) increased competition in industry with improved incentives for cost reductions.

5. Getting away from nuclear power, what is your opinion of the Isotopes Development Program which was authorized prior to your joining the Commission? Do you feel that AEC is giving adequate support to the peaceful application of radiation? Do you feel the radiation industry should be doing something it isn't to speed peaceful application?

The Isotopes Development Program will, I believe, prove to be one of the best atomic investments the nation has made to rapidly enhance its welfare, economy and international prestige. Had I been a member of the Commission when the IDP was considered, I would have enthusiastically endorsed it, as I do now, as a principal facet of our peaceful atomic energy development.

The IDP stems from the wide gap existing between rapidly advancing nuclear technology and a realization by industry and the country of the benefits to be gained from applying this technology in all fields. The major activities of this program provide a frame-work to support the peaceful applications of isotopes and radiation. In light of the benefits and potentials of isotopes and radiation, one could readily justify a level of effort several times greater than at present. The IDP is new, however, and we consider it prudent first to carefully define immediate development needs and long-range program requirements. Necessary levels of support in the future will depend upon the unfolding of new techniques and opportunities and upon the pace of closing the gap between potentials and their realization.

We are encouraging industry to undertake privately all the isotope and radiation development work it possibly can. However, a majority of industrial companies developing isotope applications are small concerns with limited financial means for undertaking required development programs. In the field of high-intensity radiation, the government is at present the sole source of massive quantities of radiation power from radioisotopes, fission products and reactors and, consequently, must see that the radiation is provided and used with benefit to the national economy.

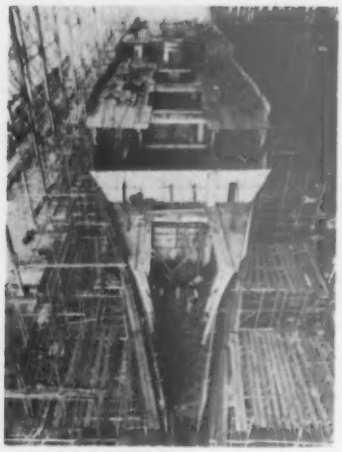
As the atomic industry grows one can foresee increasing amounts of radiation as a useful by-product or even a major product of reactors. Development of this field is an integral part of developing peaceful uses of atomic energy. To the extent its financial and technical resources permit, it is my impression that industry in general is doing the best it can to develop isotopes and radiation applications.

LATE NEWS AT PRESS CLOSE

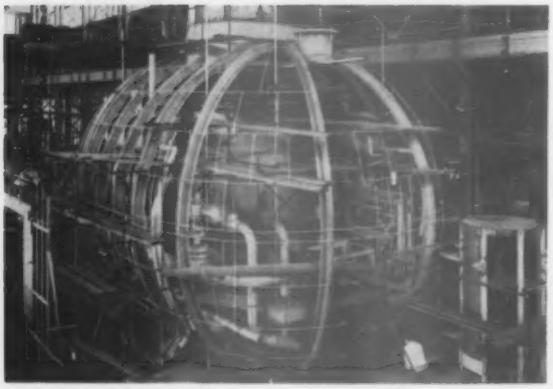
- The President approved Federal construction of a $168-million, 15-Bev (later 45-Bev), two-mile-long linear accelerator at Stanford Univ. His science advisors also urged upping outlay for accelerators from $59-million in fiscal '59 to $135-million/yr by fiscal '63.
- NUCLEONICS' London Bureau reports: breakup of the English Electric–Babcock & Wilcox Ltd. group is in sight; English Electric is reported entering a close tie with Atomics International; the fifth consortium, Atomic Power Constructions Ltd. (Richardsons Westgarth, Crompton Parkinson, Fairey Aviation, others), will get the Trawsfynydd job, its first; Fairey has developed an outstanding, annular, fuel element for it.
- AEC was reported having second thoughts last month about supporting one or more privately-built test reactors (NU, March '59, 24). Under study was this alternative—AEC construction of a large, high-flux facility.

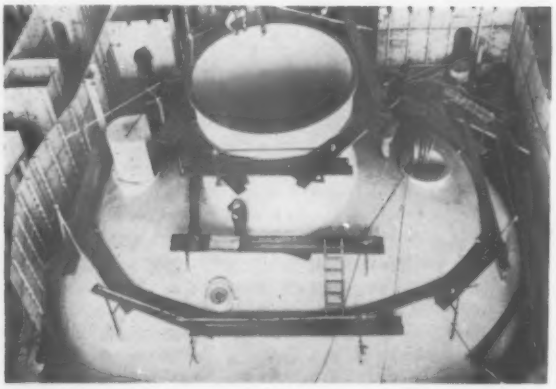
Presenting: World's First Nuclear Merchant Ship . . .

ONLY A DREAM 2½ years ago, N. S. Savannah takes on ship's shape on the ways of New York Shipbuilding Co. at Camden, N. J. She will be launched July 21. Compare this photo of an exact scale model with artist's conceptions, NU, Sept. '57, 114, and Nov. '58, 78.



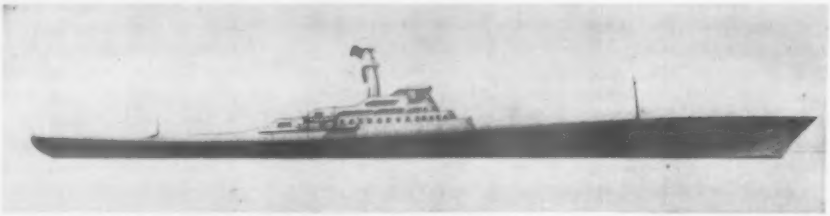
Photos taken last month show *Savannah* less than three months before her launching, set for July 21 with Mrs. Dwight D. Eisenhower as sponsor. In bow view (*left*), highest plates are A-deck; note cylinder (near top of photo) which is access tube to reactor containment envelope. Photo (*right*) shows how envelope is installed; close-up (*below, right*) shows envelope in detail. Full-scale mockup (*below, left*) was built to help plan installation of primary components in envelope. The 105-ton, 28-ft high reactor vessel was shipped last month from Babcock & Wilcox's Ohio shops and has been installed; the 21 control-rod drives are being tested tilted 30° from vertical.





. . . And a Candidate for World's First Nuclear Tanker

MARITIME Administration's conception of the tanker it wants Congress to authorize this year (NU, April '57, 85). The 60,000 deadweight ton T-7 tanker would be 827 ft over-all, 104 ft in beam, with 30,000 shaft hp, 525,000 bbl capacity, a crew of 49.



British Plan A-Ship Start, Study 8 Bids; Other News

The cause of a first British nuclear merchant ship took a sudden big step forward last month.

Eight competitive reactor designs for Britain's first nuclear merchant ship—by seven industrial groups and the Atomic Energy Authority—are under urgent technical review by the Admiralty's Civil Lord's Committee. After full assessment, the project will be "pressed forward with all possible speed," the Admiralty says; "the goal of the Admiralty committee is the economic nuclear merchant ship."

Only three of the eight are gas-cooled. Several show great technical innovations. All claim comparable or even cheaper fuel costs per shaft horsepower than oil-fired plants. Three could be put to sea in three years.

One bid is by a new group, Mitchell Engineering Ltd. of London and Fairfield Shipbuilding & Engineering Co. of Glasgow, who, together with Combustion Engineering, Inc., of New York, are offering a boiling-water reactor.

General Electric Co.–Simon Carves claim a major breakthrough with a horizontal, compact version of the Windscale Advanced Gas Reactor. The AEA itself offers an adapted AGR. De Havilland nuclear group submits a version of the High Temperature Gas Cooled design. AEI–John Thompson offers boiling water; Babcock & Wilcox Ltd., pressurized water; Hawker Siddeley Nuclear Power Co., organic moderated; Vickers Nuclear Engineering, steam cooled, heavy water moderated.

H. W. Bowker, head of AEA's marine group, says—with a new optimism that the British didn't display on the subject at Geneva last September—that nuclear ships can operate at costs 5% higher than conventional by 1961, and be fully competitive in ten years.

On the Nuclear Waterfront

Other developments last month:

• Electric Boat division of General Dynamics has gotten a second, $37,681 contract from Maritime Administration to continue development work on nuclear submarine tankers. The new job covers design work and experimental hydrodynamic research including model tank-testing to determine optimum hull proportions and controllability for a 20-knot, 20,000-ton sub tanker. Previous studies had shown an undersea craft of this size to be feasible engineeringwise.

• The keel for the Navy's first nuclear destroyer was laid May 15 at Bethlehem Steel's Fore River Shipyard, Quincy, Mass. (NU, Nov. '58, 28). To be delivered in January 1962, she will be named *Bainbridge*, for Commodore William Bainbridge, a War of 1812 naval hero.

• The Charleston (S. C.) Naval Shipyard plans to set up a nuclear power division. It announced recently it was hiring four engineers for training in the field. Construction has started at the Naval Ammunition Depot at Charleston on Polaris missile facilities, and the navy yard will be equipped to handle repairs on Polaris subs. Lockheed, which moved to enter the naval program recently (NU, May '59, 35), will supervise the work; the firm is prime contractor for the Polaris missile.

• The Pentagon said it would award contracts early in July for three more Polaris subs authorized by Congress last year. They will bring to 33 the number of A-subs completed or under construction.

• *Skipjack*, the Navy's sixth A-sub and first of the whale-shaped, high-speed attack subs, was commissioned, after going faster and deeper than any submarine had ever gone before.

• The U. S. signed agreements with Britain and France providing for cooperation in developing nuclear weapons and A-subs. Britain would get enriched uranium for the core of the Westinghouse-built reactor to propel H.M.S. *Dreadnought* (*see p. 30*) as well as design information on construction of nuclear-powered submarines; France would get the fuel but no information (basically because of the existence of a large Communist party in France). President De Gaulle has been pressing for a U. S.-built submarine reactor.

Amendments to Euratom Act Asked on Fuel, Patents

AEC has proposed two amendments to the Euratom Cooperation Act: (1) language authorizing use of a fuel-guarantee formula proposed by AEC last fall (NU, Jan. '59, 24), which relates AEC guarantees to the $90-million ceiling on fuel subsidies; and (2) language making it clear that AEC will obtain license rights only on fuel elements covered by its guarantees.

AGENCY ACTIVITIES

Quickening activities of the International Atomic Energy Agency in Vienna last month produced these highlights:

• A "functional laboratory" is to be built at Siebersdorf near Vienna, next to Austria's first reactor, now building. IAEA accepted the U. S. offer to contribute $600,000 for construction and equipment including a research reactor and a radioisotope facility.

• U. S., U. K. and U. S. S. R. delegates signed agreements formalizing the offers made by those countries to sell 5,000, 20 and 50 kg respectively of U^{235} to IAEA. The Agency now has 5,140 kw available (the U. S. is matching offers of other countries). The agreements do not contain the "hold harmless" clause so far a part of most bilaterals; this would make it more advantageous for a have-not country to get uranium from IAEA.

• A technical assistance survey mission left for Formosa, Japan, the Philippines, South Korea and South Vietnam; another is going to Argentina, Brazil and Venezuela. Technical experts are going for longer periods to Burma, Greece and the United Arab Republic.

• A study will be made of the possibility of setting up one or more isotope training centers in the Middle East (Turkey and U.A.R. wrangled over IAEA aid to existing centers at Ankara and Cairo).

• South Africa has offered to supply 1,000 tons of uranium oxide to IAEA at $18/kg, dropping its price from $21 quoted in January to meet a Belgian offer at $18.

• Voluntary cash contributions now total $1,046,414 to IAEA's General Fund, intended for technical assistance, fellowships and training. $1.5-million is sought.

Nuclear Blimp Offered

Goodyear Aircraft Co. said it could build, for 1963 operation, a 540-ft nuclear blimp (three times larger than the Navy's present anti-submarine patrol blimps) to travel at 90 mph at 10,000 ft altitude. The blimp's buoyancy would permit use of a reactor with one-twentieth the power needed to lift an airplane.

Plutonium Plant Opened

Argonne dedicated its $4-million Fuel Fabrication Facility to do research and development on plutonium fuel elements (NU, June '58, 21).

AEC's Inspection Team: Small But Effective

Fourteen years after Hiroshima and Nagasaki, it is generally assumed within the nucleonics industry that public wariness of nuclear energy is such that a major nuclear incident could wipe out years of effort by government and industry. This latent "scare" capability of radiation—demonstrated most recently by the excitement over fallout—has given unusual importance to safety in the nucleonics industry. It has also helped to make a little easier the task assigned to the 50-man inspection organization of AEC.

A ROUNDUP Feature

"Accidents can cost more than safety, particularly in this industry," an AEC official points out. "Most people and most managements realize this. Therefore, there is little [AEC-industry] conflict in this field. . . . The old saw that 'safety is money' is not an old saw in this business."

The Division of Inspection and the Division of Military Applications are the only divisions specifically established by Congress in the '54 Atomic Energy Act.

"The Inspection division," the 1954 Act sets out, "shall be responsible for gathering information to show whether or not the contractors, licensees, and officers and employees of the Commission are complying with the provisions of this act (except those provisions for which the Federal Bureau of Investigation is responsible) and the appropriate rules and regulations of the Commission."

Two aspects of the division's organization stand out: it's small and it's decentralized. Division Director Curtis A. Nelson, who has been in charge since the division was organized late in 1954, has less than a dozen professionals working for him at Germantown; some 40 others work out of AEC operations offices—inspecting materials licensees under rules established by Nelson's office.

Of the division's three branches only one concerns itself with the nucleonics industry as such: this is the **compliance** branch under Marvin Mann. The other branches—**management appraisal** and **investigation**—concern themselves with internal matters such as the efficiency of AEC's divisions and operations offices and the investigation of complaints against the Commission or its contractors (for example, injury claims from people near the Nevada test site).

Mann's four-man compliance branch has inspection responsibility for all licensees (there are 3–4,000, who hold 6–8,000 licenses of both the facility and materials type). Mann and Peter A. Morris make up a reactor-inspection team with full responsibility for inspection of these facilities; the materials-inspection process is a delegated one managed by L. David Low (administration) and Claire C. Palmiter (technical). Ground rules for materials-licensee inspections are laid down by the compliance branch but virtually all inspections are made by personnel of the operations offices.

EFFECTIVENESS

Mann's compliance group confidently contends it has done a good job with radiation safety despite its small staff. The accident record among the 3–4,000 licensees tends to support this. There have been no fatalities in the two-plus years during which the inspection program has been fully operational and only a handful of minor over-exposures to radiation. The branch has no jurisdiction over government facilities.

In the most recent full year—1958—there were four incidents at reactor facilities (none involving the reactor itself) and 18 nonreactor incidents. None of these involved more than a few roentgens of radiation exposure.

The safety record for the licensee program is good, the compliance branch asserts, because (1) AEC's inspectors have hammered away at basic safety precautions such as proper supervision and adequate procedures; and (2) because of management's recognition that safety is an unusually large economic factor in the nucleonics field.

"We feel," says Mann, "that management, organization and procedure are the keys to safe operation. There is no question but what technical talent and experience are necessary in many operations. But technical talent and experience are, in our view, not sufficient by any means. . . .

"You've got to have a good procedure and supervision has to see that it is followed. The operator [at the console of a reactor] really doesn't have to know any more about a neutron than the newsboy down on the corner."

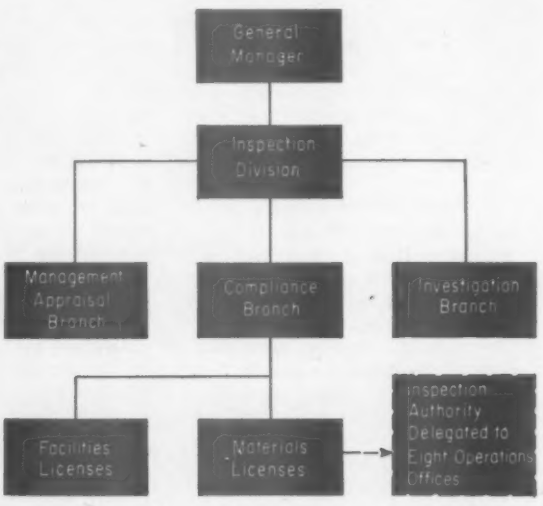
A critic of the AEC inspection system has had this to say: "You can judge the effectiveness of the Inspection division by the paucity of the inspectors." Nelson, Mann & Co. argue, in rebuttal, that this is a fallacious argument having no bearing on the real goals of an inspection system: to educate the users in safety consciousness and to encourage the wide adoption of effective safety procedures.

"To put a man 24 hours a day on a licensee is, in effect, relieving management of its responsibility for safe operation," Mann insists. "In that situation you have divided responsibility—and there can be no more potent force in the direction of unsafe operation."

The entire inspection force—at both headquarters and operations offices—has been increased by 5–6 men in the current fiscal year and the total will be brought to about 60 during fiscal '60.

"If the number of licensees should increase sharply over the next couple of years, we would expect to adjust the number accordingly."

Unlike most other compliance agencies, the branch has no authority to demand action by a licensee. It is



Nelson Mann Morris Low Palmiter

not an enforcement agency; rather, as stated by the '54 Act, it is "responsible for gathering information." Its formal course of action is restricted to discussion of a problem with a licensee and the filing of recommendations for action by the AEC general manager.

In the manner of a law-enforcement officer giving a lecture instead of a ticket, however, AEC's inspectors are able to do much informally to promote compliance. The inspectors enter a licensee's place of business with a 4-point check list: specific compliance with the license, regulations and law; over-all safety; management effectiveness (attitudes and qualifications of the managers themselves); and effectiveness of the safety procedures.

First step is to discuss with management the purposes of the inspection system—the "educational process." After the inspection is made there are further talks:

"We sit down with management and tell them what we see and how it strikes us. . . . We do not suggest specific action to a licensee. If we did suggest specific solutions we would no longer be objective. We can—and do—point out areas of difficulty.

"However, we make it a point to discuss with the licensee what will be reported to the general manager. Frequently, the licensee takes action before the inspector leaves the site. . . . "

Another major difference between AEC's and other compliance agencies is the importance of technical know-how to the inspector's qualifications. AEC personnel must not only expertise themselves on the law and regulations but they must be technically experienced, as well, in the handling of radioactive materials. Also, they must know how to deal with management.

Mann on Safety:

"I believe that to attain consistently safe operation with radioactive materials and nuclear reactors it is necessary that an operation be independent of the vagaries and idiosyncracies of individuals.

"One basic approach to such independence is the proper use of appropriate (written) procedures. 'Proper use' of procedures implies undeviating use by persons trained and skilled in the procedures themselves. These people need not have any other special training. 'Appropriate procedures' are those that are technically sound, practical in application, and complete in coverage. All normal operations and all conceivable abnormal operations (emergencies) should be dealt with in detail.

"Finally, the fulfillment and maintenance of these objectives require a system for periodic supervisory or managerial review. By such a system, management is able to discharge its principal responsibility for safety."

REACTOR INSPECTION

Hanging on a wall of the compliance-branch office is a bar chart showing at a glance the last visit to each of the country's non-AEC reactors—about 40 in operation and another 10 in various stages of construction. Mann and Morris have personal responsibility for the inspection of these plants. They get help from qualified people in the Chicago and San Francisco operations offices—but during these inspections the operations personnel are on temporary detail and report directly to Mann.

Officially, Mann and Morris enter the picture when a construction permit is issued; unofficially, they take an interest much earlier to get a feel for the safety aspects before construction gets started.

"As often as is practical," Mann explains, "we sit in on the design of the reactors. . . . We pay visits to the designer to become acquainted with the machine."

In its simplest terms the inspector's job is to check out the machine and the people who run it: "The facility and its design determine the potential for hazard. Depending on the people, the potential hazard can be (1) minimized, (2) unchanged or (3) realized."

While Germantown has not delegated authority for reactor inspections, the day is not too distant when it will probably relinquish responsibility for research-type reactors to the operations offices (laying down inspection ground-rules but letting operations people make the inspections).

As the compliance branch is moving toward a delegation of its reactor-inspection authority, so the AEC itself is moving toward a delegation of some of its over-all inspection authority. The Commission recently completed its first informal cooperative arrangement with a state government—Connecticut—to bring state-level inspectors into the picture for small users like doctors; also, AEC has suggested to Congress that the '54 Act be amended to permit formal agreements of this type (NU, May '59, 27). Well over half of AEC's licensees fall into this small-user category and sit near the bottom of the inspection-priority list (inspection every 2–5 years).

In fact, only some 30% of licensees have operations which are felt to require inspections at least once a year. At the top of the list now are reactors (as many as one inspection a month) and other major facilities such as fuel-fabrication plants; also high on the list are radiographers who use multicurie sources for non-destructive testing and the more complex industrial and hospital operations.

On the basis of its more than two years of inspection experience, AEC is conducting a major revision of its priority list and the result will be a downgrading in the importance of some operations and an upgrading of others.

AEC Proposes Changes in Indemnity Rules, Act

The Atomic Energy Commission is moving to close "gaps" in its indemnity regulations under the Price-Anderson Act. And, in addition, Congress appears willing to go along with AEC suggestions for amendment of the Act itself. At the same time, however, bipartisan sentiment is growing within the Joint Committee on Atomic Energy to go slow on the Euratom program and any nuclear-merchant-ship program until knotty indemnity problems are solved in those areas.

Rep. Chet Holifield (D-Calif.), in charging foreign nations with foot-dragging on the indemnity problem, commented that "it's time to fish or cut bait." His comment came at hearings of the Joint Committee on Atomic Energy last month on the Price-Anderson Act. AEC spokesmen used the occasion to announce issuance of a proposed revision of its temporary regulations. Principal features are:

1. The method for determining the amount of financial protection or insurance required of licensees would be modified, and the minimum requirement would be raised.

For all power and testing reactors, and for other types with thermal power levels above 10 megawatts, financial protection required would range from $3.5-million to $60-million. Although the thermal power level would still be the basic guide, population density around the reactor would be taken into account.

Financial protection of $1-million would be required for other reactors with thermal power levels not exceeding 10 kw, $1.5-million for 10-kw-to-1-Mw reactors, and $2.5-million for 1-to-10-Mw reactors.

2. Financial protection of $1-million would be required of construction permit holders who are authorized to possess and store special nuclear materials at the reactor site before the reactor goes into operation. AEC indemnity coverage would go into effect at the same time.

3. Procedures would be provided for exempting federal agencies and non-profit educational institutions from the financial protection requirements. Commission indemnity would still be available.

The industry was invited to submit comments on the proposed revisions during May.

Amend the Act

Harold L. Price, director of AEC's Division of Licensing and Regulation, also recommended two revisions of the Price-Anderson Act.

One would make it clear that government indemnity does not cover property on the reactor site, since commercial insurance for such property is available up to $60-million. The other is aimed at filling the "gap" in coverage which could result when one nuclear incident has occurred, and the licensee has not had time to obtain reinstatement of the full value of his policy. AEC would be authorized to fill the coverage "gap" until reinstatement can be renegotiated.

Both Republican and Democratic committee members put both AEC and the foreign governments on notice that their patience is wearing thin on a European liability solution —that congressional support of the Euratom program hinges on a solution to the foreign liability puzzle.

"We are facing pretty soon an authorization bill which carries $14-million for Euratom which might be made contingent on the possibility of remedying these problems," said Rep. Carl Durham (D-N. C.).

Committee members also warned against any assumption that Congress will extend Price-Anderson or Savannah-type indemnity to nuclear-propelled merchant ships.

When Richard P. Godwin of AEC's Maritime Reactors Branch testified that discussions among the U. S. and other nations are still in the "formative" stage, Holifield commented:

"What the maritime people and the insurance companies are waiting for now is for us to bail them out as we bailed out the reactor builders in the U. S."

Compulsory Licensing Set for Another Five Years

Another five years of tough patent policies by the Atomic Energy Commission is in store for the nucleonics industry. Extension of the compulsory licensing provision of the 1954 Act was virtually guaranteed in late April when AEC asked Congress to extend it for five years beyond the Sept. 1, 1959, expiration date.

Appearing at hearings of the Joint Committee on Atomic Energy, AEC General Counsel Olsen said:

"Some have asserted that the time is past when a few contractors can secure a preferential position with respect to technology or patents by virtue of being contractors. It is believed that the possibility for preferred positions still exists.

"While the AEC has a large number of contractors, both large and small, most of the programmatic research and development is performed by relatively few contractors. Today approximately 90% of the inventions reported under Commission contracts have been reported by some 14 Commission contractors."

Only one industrial spokesman and a few patent attorneys and association spokesmen showed up at the JCAE hearings to plead industry's case for greater private development of atomic energy through patent incentives.

JCAE's Chet Holifield (D-Calif.), an advocate of compulsory licensing, commented on industry's "apparent satisfaction" with present law and said he was "extremely" disappointed more AEC contractors didn't testify.

Forum, ANS Pull Out Of Nuclear Congress

Ending an uneasy partnership, the American Nuclear Society and the Atomic Industrial Forum have pulled out of the annual Nuclear Congress in which they have participated the last two years with the Engineers' Joint Council. The two will collaborate in staging one major conference in the fall of each year.

ANS and the Forum will be joined by the annual Hot Labs and Equipment Conference, which last month reorganized as a professional division of ANS.

The Forum plans to resume sole sponsorship of its annual trade show, Atomfair, next year and is polling its members to determine exhibitor response to the idea.

EJC meanwhile plans to continue its own series of Nuclear Congresses, and says it will continue its association with the management conference sponsored by the National Industrial Conference Board.

The Forum-ANS annual meetings will be staged within one week, with the Forum sessions Monday through Wednesday, the ANS sessions Wednesday through Friday, and the Atomfair Monday through Thursday. Present plans call for such coordinated meetings in Washington this fall, in San Francisco in 1960 and in New York in 1961.

The Forum published a compendium of 56 excerpts from letters received by it in response to a call for comments on the action; most of them appended the adjective "heartily" to the verbs "agree" or "concur."

Reactor News

PG&E PLANNING THIRD A-PLANT

Pacific Gas & Electric Co., first U. S. utility to generate nuclear electricity (at GE's 5-Mw(e) Vallecitos reactor) and now building the 60-Mw(e) Humboldt Bay boiling-water plant, is considering a 200–350 Mw(e) reactor to be built in the San Francisco Bay area for 1965 completion, president Norman R. Sutherland said. Decision to build it depends on achieving a design to attain 6½ mills/kwh power cost. "We are looked on as a bit loony," Sutherland confided to reporters, "but we think nuclear power can be competitive in five years, not 10 as some of the people in the East think." Meanwhile the turbine design for Humboldt Bay has been upped to 70 Mw (original reactor design was for 50 Mw output).

CANADA STARTS ORGANIC PROJECT

Atomic Energy of Canada Ltd. has awarded a $600,000 contract to Canadian General Electric Co. for a design study and development work on an organic-cooled power reactor. The unit would still use heavy water for moderation and natural uranium as fuel, as in all other Canadian reactors (except the two swimming-pools). Interest in organic cooling has been growing in Canada as polyphenyls cost 40¢/lb while D_2O is $28/lb; it's felt an organic-cooled nuclear plant might not only be economic for Canadian power stations generally, but also particularly attractive for remote—such as Arctic—locations. In fact the Department of Northern Affairs and the Northern Canada Power Commission participated with AECL in the decision to embark on OCDRE (Organic Cooled, Deuterium Reactor Experiment).

TRIPLE ADVANCE FOR SUPERHEAT REACTORS

Nuclear superheating was much in the news last month:

1. **Vallecitos.** In an experiment carried out in an in-pile demonstration loop in the core of the Vallecitos boiling reactor, superheated steam was produced last month. The experiment, called SADE (for Superheat Advance Demonstration Experiment), uses uranium oxide fuel to superheat steam from the reactor. Special instrumentation measures steam temperature, pressure and flow in the process tube in the core. First phase of the program will last several weeks, has as its objective to demonstrate feasibility of using steam as a reactor coolant; long-range use of VBWR for superheat fuel development is planned, as part of General Electric's Operation Sunrise (NU, Nov. '58, 19).

2. **AEC.** Eight proposals have come in to AEC in answer to its call for bids to do engineering development work on promising concepts and materials for advanced reactors producing superheated steam (NU, April '59, 18). They came from American Standard's new Advanced Technology Laboratories division; Atomics International; Battelle; Combustion Engineering; General Electric; Nuclear Development Corp. of America; Nuclear Metals; and Westinghouse.

3. **Northern States.** AEC announced completion of the contract modification whereby Northern States Power Co. is authorized to use the two-region superheating core designed by Allis-Chalmers (NU, April '58, 22; March '59, 25) for the 66-Mw(e) boiling reactor to be built at Sioux Falls, S. D.

To round out the picture of superheat activity, NUCLEONICS ascertained the state of progress on the two other projects in this area. Argonne is progressing with design of **Borax-5**, which will be built on the site, and use as much as possible, of the dismantled Borax-4 at the Idaho test station (NU, Jan. '59, 27). A new pressure vessel to sustain the higher pressures will be built, a new pit will be dug, the building will be enlarged, and instrumentation modified, but the old 3.5-Mw turbine, water-supply system, etc., will be reused. Construction is to start this fall for completion next spring and criticality early in summer 1960. And AEC is evaluating a preliminary design submitted recently by General Nuclear Engineering Corp. on **BONUS** (BOiling NUclear Superheat), the 15-Mw(e) plant being developed for Puerto Rico (NU, Dec. '58, 26). AEC may undertake some research and development work to carry the project further; meanwhile GNEC is working on a more detailed design.

KAISER TO BUILD HANFORD REACTOR

AEC has chosen Kaiser Engineers from among 14 firms bidding to be principal constructor on the new plutonium production reactor, ninth to be built at Hanford. The $145-million pressurized-water graphite-moderated unit, authorized by Congress last year, is being designed by General Electric, operator of Hanford, with Burns & Roe as architect-engineer for the supporting facilities. Kaiser, which built the last two Hanford reactors, will get a cost-type contract, four years to carry it out.

Reversing previous Administration policy, AEC chairman McCone announced acceptance of convertibility for the big reactor. (JCAE had insisted last year that the plant should be designed for an eventual dual-purpose role, being built at first as a production reactor only but with features incorporated permitting its conversion later for power take-off as well. President Eisenhower himself termed the project "unsound," criticizing it in general and the convertibility plan in particular.) The output of the reactor, when and if converted, has been placed at 300–900 Mw(e); if it reaches the latter figure, it would be by far the world's biggest. Britain's two Hinkley Point reactors, each with 250-Mw(e) capacity, are the biggest now actually under construction, and Britain recently announced plans for a pair of 500-Mw(e) units.

CULLED ON THE REACTOR CIRCUIT

Armour Research Foundation will increase the power level of its Atomic International solution-type research reactor from 10 to 100 kw. . . . Martin Co. and H. K. Ferguson have collaborated to design a 45-Mw(th) pressurized-water process-heat reactor that could deliver 150,000 lb/hr saturated steam at 150 psig, 366° F, for 70¢/10⁶ Btu. . . . North Carolina State's 500-watt homogeneous reactor, first U. S. private university unit, has been dismantled for relocation on the campus (NU, June '57, 28); a new 10-kw reactor, to be completed this fall by Nucledyne Co., is going into the old shield.

HUNGARY'S REACTOR CRITICAL; REDS BUILD 2

The first reactor in Hungary, at Csillebérc in the suburbs of Budapest, went critical March 25, it was announced last month. The 2-Mw Russian-supplied pool-type reactor is identical to units already operating in Czechoslovakia, Poland, Rumania and East Germany, and one not yet reported working in Bulgaria (a larger, 10-Mw(th) version is in operation in China and nearing completion in Yugoslavia). The Hungarians are now planning to build a subcritical reactor for use in designing a small power unit. . . . A previously unreported research reactor has been completed in Latvia, NUCLEONICS learns; a 1-Mw unit has been started in Byelorussia.

ROUNDUP

World News

France's G-2 on the Line . . .

First commercial production of nuclear power in continental Western Europe began April 22 when G-2 at Marcoule began feeding electricity into the French grid. G-2 had first gone critical for physics testing last July (NU, Aug. '58, 19). Output was 130 Mw(th), 9 Mw(e); over the next few weeks the reactor will be taken up to full power of 150 Mw(th), 25–30 Mw(e). G-3, an identical twin, is slated to go on the line in about six months. Like Calder Hall and Chapel Cross in Britain, G-2 and G-3 are dual-purpose reactors built primarily to produce plutonium for defense.

. . . Chapel Cross Also

Ten days later Britain placed her second nuclear power plant, at Chapel Cross in southwest Scotland, in operation when on May 2 the first of four reactors identical to the four at Calder Hall went on the line. It had first gone critical in November (NU, Dec. '58, 26).

Pot Stewing in Italy

Engineer Gino Martinoli resigned as president of AGIP Nucleare, NUCLEONICS learned, following a rift with Enrico Mattei, head of ENI (the state-controlled gas and oil monopoly with responsibility for national energy sources), over the high cost of AGIP's Calder-type nuclear power plant at Latina. This comes on the heels of the resignation of Prof. Carlo Matteini from the presidency of SENN. The struggle of the technicians against the state industries and political functionaries is gaining momentum, and the present private-industry-minded government is seen as watching more closely the operations of the state industries such as ENI. Observers feel although the technicians may have lost this round, they now have the government more nearly with them than before. . . . Newly-elected president of SENN is Tommaso Zerbi, professor of economics at Palermo Univ.

First Big German Order Near, B&W Leads

AKS,* a German utility combine, is on the point of placing the first German order for a full-scale power reactor and the first under the joint U. S.–Euratom program. Reports to NUCLEONICS are that Babcock & Wilcox is in the lead, ahead of Westinghouse and General Electric, to get the order. B&W offers a pressurized-water reactor of 165–180 Mw(e) at about $240/Mw(e) capital cost (excluding land and interest). Fuel costs would be 1.2 pfennig (0.24¢)/kwh, total power cost 3.8 pfennig (0.76¢). Only the reactor would be imported from the U. S.—conventional equipment would be built in Germany (Brown, Boveri & Co., Mannheim, would furnish turbines and generators)—and this decision to let German firms participate as much as possible has reduced the price considerably over B&W's initial offer. NUCLEONICS also learned that RWE is likely to ask also for a detailed offer from B&W, but has not yet done so.

Sweden Delays R-3, Turns Abroad for A-Power

Completion of Sweden's R-3–Adam reactor has been delayed again: it will not go critical until 1962, on the line until 1963. Last fall Adam was dropped as a separate project and combined with R-3 (NU, Oct. '58, 30); originally R-3 was to be operating by 1960–61. Reasons are understood to be: need for a larger rock chamber than has been excavated, need for additional underground structures and steel-clad concrete walls, and longer assembly time. Simultaneously, the State Power Board decided to invite bids for reactors of foreign types, for 1965 operation. If economically and technically feasible, the Board will build such a plant as preparation for a program to add 250 Mw(e) of nuclear power per year in the early 1970's. These plans will not interfere, the Board emphasized, with development of Swedish-designed reactors.

Rolls-Royce 1st U. K. Firm to Make Fuel

Fuel elements for Britain's first nuclear submarine H.M.S. *Dreadnought* will be fabricated by Rolls-Royce, first break in the monopoly the Atomic Energy Authority has held on fuel fabrication. Prime Minister Harold Macmillan told Commons last month that the Admiralty would supply uranium to Rolls-Royce, which is Britain's designated agent for purchase of a Westinghouse S5W (*Skipjack*-type) submarine reactor, and prospective builder of the reactor for the second British A-sub. Macmillan made it clear the uranium would remain the property of the Admiralty.

Red Ink for AEI—John Thompson

With more than half the construction period for Britain's Berkeley nuclear station behind, it's possible to estimate final outcome of AEI—John Thompson Nuclear Co.'s contract as a "substantial loss," said Lord Chandos, chairman of Associated Electrical Industries. The firm was also in the red for the year on its total nuclear work, including three research reactors.

Nuclear Straws in the Wind from All Over

Atomic Energy of Canada Ltd. made its first shipment of Canadian-made fuel elements abroad last month. The 290 54-lb rods of natural U were sent by air to Switzerland for use in the heavy-water research reactor P-34 now building at Würenlingen. Also, Eldorado Mining & Refining Ltd., Canada's Crown company for marketing natural uranium, announced successful testing of 3 tons of the metal to be shipped to Japan for the account of the International Atomic Energy Agency. . . . The Japanese themselves, however, were less fortunate with their first batch of uranium produced in their newly-completed refinery (NU, May '59, 34): the 352 lb of yellow cake from South Africa contained, after refining, excesses of impurities including 130 ppm each of nickel, iron and aluminum, 220 ppm carbon, and 40 ppm nitrogen. Perplexed engineers think the metals may have come from the production water or from inadequate cleaning of the facility. Production is suspended pending full investigation. . . . A Nuclear Institute of the Austrian Universities has been set up by the Austrian Ministry of Education. It will be responsible for operation of Austria's second reactor, the Triga. . . . Pintsch-Bamag of Butzbach, West Germany, has an order from the West German Atomics Ministry to build a heavy-water pilot plant, capacity 0.5 tons/yr. It will start construction next year near Frankfurt, next to the 6-ton/yr plant built recently by Höchst. P-B has long been working on its hot-cold, H_2S process (NU, Nov. '56, R11). . . . Atomics International has shipped a 10-watt solution-type (L-77) laboratory reactor to Mayagüez, Puerto Rico, for the island's Nuclear Center. AMF Atomics is also building a pool-type research unit there.

* AKS stands for Arbeitsgemeinschaft Baden-Württemberg zum Studium der Errichtung eines Kernkraftwerkes Stuttgart.

News in Brief

1959: The Year of Consolidation

With more than half of its life still remaining, the year 1959 appears already assured of a unique title: "The Year of Consolidation in the Nucleonics Industry." Last month, the eighth, ninth and tenth mergers of the year were consummated when Allis-Chalmers acquired the Nuclear Products group of ACF Industries (see below), Baird-Atomic purchased four smaller firms, and Packard-Bell Electronics acquired a majority interest in Technical Industries Corp., Pasadena, Calif., a new nuclear-instrument firm.

Acquired by Baird-Atomic for an unspecified amount of stock were: Atomic Associates of New York and of California, Atomic Accessories, Inc., (and subsidiary, Atomic Film Badge Corp.), New York, and Atomic Development and Machine Corp., New York. Baird had held minority interests in both Atomic Associates organizations.

Allis-Chalmers Strengthened by ACF Purchase

A stronger, more diversified reactor manufacturer—Allis-Chalmers—has emerged from A-C's purchase of the commercial reactor operation of ACF Industries. To its know-how in boiling-water and fusion technology, A-C has added a 190-man force with capability in boiling-water (Elk River), gas reactors (AEC's Oak Ridge project) and test and research reactors. ACF's management was reported as unhappy with the lack of profits to offset the liability risks of its commercial-reactor business. Board Chairman William T. Taylor said "it has become evident that future rewards in the commercial reactor field will accrue principally to companies dominant in the power-equipment industry."

Who Will Buy My Betatron?

The Univ. of Chicago last month announced two "nibbles" to this advertisement placed in several U. S. newspapers: "FOR SALE: 100-million-volt Betatron. Fully equipped 100-million-volt electron accelerator in good operating order, built by General Electric Corp. Has served as a fine instrument for basic research laboratory. Address: Clement Mokstad, Univ. of Chicago." Inquiries to buy the 9-year-old machine came from prospects in Venezuela and Pakistan.

Southern Nuclear Compact Adopted; Ratification Next

The governors of 15 southern states have approved the Southern Interstate Compact on Nuclear Development, after watering it down to exclude all regulatory activities. It will become effective after ratification by seven states and Congress. First of its kind in the U. S. and first industrial compact in the South, the agreement's main aim is to provide a climate in which nucleonics firms will be attracted to the area. While joint research facilities are authorized, the accent will be on services to the member states—in training, dissemination of information, help for regulatory officials and promotion of the industrial atom.

AEC Official Hints Expiration of Canadian U Options

In a mid-April speech to the Wyoming Mining Assn., Jesse C. Johnson, director of AEC's Raw Materials div., has hinted that the U. S. will not take up options to buy Canadian uranium when these options expire March 31, 1961. Looking beyond then to the period 1962–66, he said 84% of AEC's U purchases would come from domestic sources. While AEC also has options to buy Canadian U through 1966 at $8/lb, he added, "there is no commitment to exercise these options. . . ."

Nuclear Groups Organized in Cleveland, Detroit

Two new nuclear groups have been formed in the Midwest: the Zirconium Association, Cleveland, and the Michigan Nucleonic Society, Univ. of Michigan. The former, under Executive Director W. B. Thomas, was established to promote use of zirconium and provide a focal point for closer liaison between industry and governmental agencies. The latter, formerly the Nucleonic Discussion Group, will "promote the exchange of scientific information and liaison between workers in nuclear science."

Goodrich, High Voltage Form Space Organization

A firm to design, develop and manufacture ion-propulsion devices for propulsion of outer-space vehicles has been formed by B. F. Goodrich and High Voltage Engineering. It is Goodrich-High Voltage Astronautics, Inc., located at High Voltage headquarters in Burlington, Mass. Development of a laboratory ion-thrust unit, according to officials of the parent firms, "is well along the way." Officers of the joint venture include: A. John Gale of HVEC, president; and P. W. Perdriau of Goodrich, chairman.

Battelle Takes on Depleted-U Study for AEC

A study to define the market for depleted uranium outside the nuclear field will be completed by Battelle Memorial Institute this month. AEC commissioned Battelle to make the three-month survey in hopes of boosting purchases of the "substantial annual tonnage" which is becoming available as U-235 is removed. Nonnuclear use of depleted U has been permitted for a year (NU, July '58, 22).

Fallout, Safety, Fed-State Relations in News

Fallout from nuclear weapons, radiation safety and federal-state relations in the nuclear field all continued to make news in May as (1) the Joint Committee on Atomic Energy held a series of public hearings on the federal-state question; (2) AEC's General Advisory Committee completed a report reassuring the public on the relatively minimal danger from fallout; (3) the National Committee on Radiation Protection and Measurements announced that a revised handbook will be available in June on "Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water" (some up, some down, some unchanged); (4) AEC proposed reducing life-time accumulated radiation doses of workers in controlled areas by one-third of existing limits; and (5) a Senate subcommittee on health called hearings to lay the groundwork for possible legislation in 1960 requiring the gradual transfer of some AEC radiation responsibilities to the U. S. Public Health Service (NU, May '59, 27).

News in Brief Notes—Isotopes, UO_3 and Oil

Within ten years 5–7,000 additional radiological specialists will be required in the U. S., according to George G. Manov, technical director of Tracerlab's Reactor Monitoring Center, Richmond, Calif. Manov also estimated that 12,000 laboratories would be using radioisotopes by 1969. . . . **Mallinckrodt Nuclear Corp.** has won a contract to supply 20,000 lb uranium oxide to General Electric for eventual use in the German RWE reactor (NU, Nov. '58, 25); final shipment to GE should be made in September. . . . **Standard Oil of Indiana** has contracted with Armour Research Foundation to sponsor a diversified program of radiation research for oil, with emphasis on petroleum and petrochemical processing.

Europe Seeks Atom Independence; Market Prospects Dim

STRESA

A frenzied determination in continental Europe for total self-sufficiency both in design and construction of nuclear power stations and in fabrication of fuel elements was the most notable trend observed at the third industrial conference of the Organization for European Economic Cooperation, held last month at Stresa, Italy.

Aim of the conference, Pierre Huet, director of OEEC's European Nuclear Energy Agency, told NUCLEONICS, was to inject some realism into the nuclear scene in Europe. The short-term commercial potential for nuclear power in continental Europe has been greatly overestimated, he said. He maintained, supported by many conferees, that the Continent has five years to get acquainted with nuclear technology; subsequently it should achieve self-sufficiency and eventually competitive status in the world market with second-generation reactor types.

In an ENEA conference report, total nuclear installed capacity in Europe was put at 8,500 Mw by 1965, and annual additions thereafter at 2,500 Mw. Of this 20% would be bought in the U. S., representing a cumulative total by 1965 of $160-million, and $40-million/yr thereafter.

But this target for installed capacity and the American portion of it began to look extremely optimistic, according to a NUCLEONICS survey of the conference delegates. Several doubted whether some of the continental projects would ever get built, and thought the remainder would have a painful and protracted birth. This feeling was reinforced by announcement by the Netherlands that it was postponing indefinitely its 150-Mw(e) project planned jointly with Belgium at Mol. Italy also announced a halving of its current nuclear research program for this year.

The area for U. S. sales was seen largely confined to fuel-handling equipment, nuclear control systems, instrumentation and in special cases the vessel and core. One leading U. S. delegate told NUCLEONICS that thereafter Europe would no longer be a market for nuclear components. With the exception of Italy, speakers from continental industries maintained no real need for nuclear power existed there for the next five years.

Discussions among 500 top European management experts revealed a definite trend away from installation of large power reactors in continental Europe, toward more small- and medium-size power and research units, of both light-water and heavy-water moderated types. These two types, ENEA says, are likely to comprise two-thirds of reactors installed on the Continent by 1965.

Japanese Industry, Government Battle Down to Wire Over Policy Governing Foreign Licensing Agreements

TOKYO

The future course of Japan's nuclear technological development is at stake in the latest round of a drawn-out battle between government and industry, as the former nears a policy decision on licensing arrangements with foreign firms. The principal protagonists: the Ministry of International Trade and Industry (MITI), whose job it is to recommend licensing policy to the Cabinet; the Finance Ministry and the Bank of Japan, who, in pursuit of their traditional policy to hold down foreign-exchange expenditures, are trying to minimize licensing arrangements; and industrial groups, most or all of whom see their foreseeable nuclear future tied to foreign technology.

For more than two years, MITI has resisted all pressure from private firms for approval of nuclear-licensing agreements. For example, Mitsubishi Electric Mfg. Co. has been trying without success to go ahead with a general nuclear agreement with Westinghouse, which is its principle licensor for other heavy electrical equipment (NU, Apr. '57, 17; Aug., 27; Nov. '57, 19). Recently, Mitsubishi and other interested firms withdrew their license applications in anticipation of a new MITI policy now in formulation. When these new rules are laid down, a flood of applications is expected, including Fuji Denki with U. K.'s General Electric Co., Tokyo Shibaura with U. S. General Electric, and Mitsubishi with Westinghouse (NU, May '58, 23).

Informed sources said MITI has been struggling with four licensing problem areas:

1. Length of licenses. The Finance Ministry would like duration of licenses to be as short as possible, because it considers all such arrangements as "mortgages" on foreign exchange. But MITI is generally felt to regard 10 years as the minimum for profitable use of a license.

2. Home-made equipment. MITI is considering rules requiring maximum use of equipment made in Japan. The Finance Ministry agrees with this proposal. Up to now, however, foreign reactor contractors have been reluctant to accept Japanese-produced equipment, though there is a trend toward home-made components to take advantage of lower labor costs.

3. Royalty payments. Setting the dates for payment of first royalty payments by Japanese licensees is MITI's knottiest problem. Industry is anxious to complete the agreements and make initial royalty payments as soon as possible, in order to take delivery on technological data. The Finance Ministry, however, argues that it will be some time before Japanese firms can build reactor equipment on their own and there is no hurry in paying royalties. The industry rejoinder is that only one imported prototype is necessary to clear the way for domestic manufacture, despite the unusual demands of the nuclear field.

4. Number of licenses. The Finance Ministry would like to see the total number of nuclear licenses limited. Therefore, one argument they advance against early agreements is that the U. S. manufacturing industry has not sufficiently consolidated itself. They note the continuing debate over reactor concepts and the trend toward merger.

One industry spokesman, for example, said MITI and Finance Ministry officials had suggested that the organic-moderated concept may turn out best in the U. S. and might be worth waiting for. Industry's answer to this is that the entire U. S. program is influenced by the abundance of conventional fuel sources but that Japan must proceed faster.

Still another problem in Japan is that of nuclear liability indemnity.

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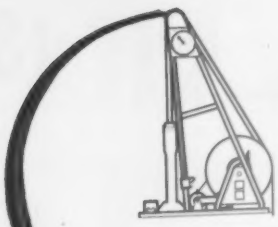


PYE

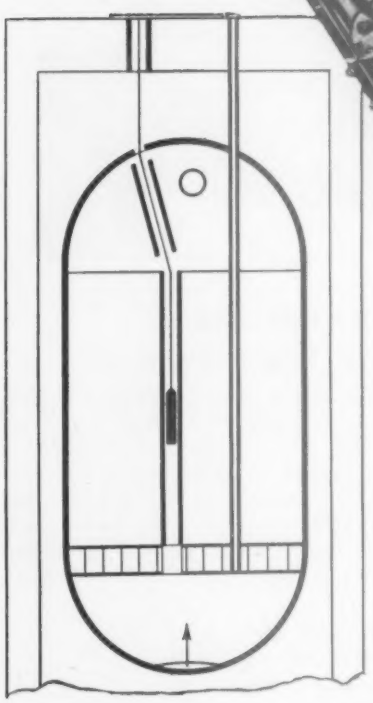
REACTOR INSPECTION
TELEVISION EQUIPMENT

REACTOR CAMERA

Television is a vital technique in the operation of gas-cooled reactors. The type of camera shown is in regular use at Calder Hall Nuclear Power Station, England; it carries its own lighting, and, in addition to visual inspection of the reactor interior, permits the removal of objects from the reactor using the special grab attachments. All the camera facilities are controlled remotely.

The camera functions satisfactorily with radiation dose rates greater than 10^6 Rads. per hour; cooling gas, carried to the camera by the supporting hose, allows operation with ambient temperature of 150°C.

Direct experience of such conditions over a number of years has enabled Pye to design cameras that will withstand high levels of nuclear radiation, temperature and pressure. Models can be supplied for use in water-cooled reactors. If you have any specialised television requirements, contact Pye Ltd., and avail yourself of their experience.



This console gives complete remote control of the camera. It carries the picture monitor and the control unit.

PYE LIMITED · ATOMICS DIVISION · CAMBRIDGE · ENGLAND

FUEL BY SYLCOR

For every type of reactor... research, production, power breeder... fast and thermal... there are representative SYLCOR fuel loadings either in the United States, Canada, Europe or the Mid-East.

Whatever your plans for a reactor, SYLCOR's production team, together with our scientists, engineers and technicians are experienced in making fuel elements, control elements, or both, for your type of reactor.

Indeed, the total of SYLCOR experience is massive, for we have now fueled more reactors, built more fuel elements... than any other commercial manufacturer.

We suggest you "Fuel by SYLCOR" to get the most in scientific and practical experience.

Meanwhile, send for "Nuclear Fuels: Key to High Performance", "Bibliography of Effect of Radiation on Solids", "SYLCOR's Package Fuel Plan" and new data sheets and detailed drawings on SYLCOR's four **Standard Fuel and Control Elements.** Write Sylvania-Corning Nuclear Corporation, Bayside, L. I., New York.

FUELED BY SYLCOR

Army Package Power Reactor, APPR-I, Corps of Engineers, Ft. Belvoir, Va.
Core 2

Army Package Power Reactor, APPR-IB.
Complete critical loading

Belgium Materials and Engineering Test Reactor (BR-2), Mol, Belgium
Complete core and critical loadings

Brookhaven Gas-Cooled Research Reactor, Upton, N.Y.
Complete reloading and spares

Brookhaven Medical Reactor, Upton, N.Y.
Complete core loading

Brookhaven Neutron Source Reactor, Upton, N.Y.
Complete core loading

Brookhaven Water Moderated Critical Facility, Upton, N.Y.
Complete core loading

Chalk River Pool Test Reactor (MITR), Chalk River, Ontario, Canada
Complete core loading and spares

Curtiss-Wright Pool Reactor, Quehanna, Pa.
Complete core loading and spares (According to Curtiss-Wright design and specifications)

Enrico Fermi Atomic Power Plant (PRDC), Monroe, Mich.
Complete core loading with blanket elements

Industrial Reactor Laboratory Pool Reactor (IRL), Princeton, N. J.
Complete core loading and spares

Israel Government Reactor, Israel
Complete core loading and spares

McMasters University Reactor, Hamilton, Ontario, Canada
Complete core loading and spares

Melusine Reactor, Grenoble, France
Complete core loading plus spares

MIT Reactor, CP-5 Type, Cambridge, Mass.
Complete core loading and special test elements

National Aeronautics and Space Administration Test Reactor, Cleveland, Ohio
Complete core loading for [illegible] year

NDA Pawling Research and Test Reactor, Pawling, N.Y.
Complete core loading

Netherlands RCN Test Reactor, Petten, The Netherlands
Complete core loading and spares

North Carolina State College Research Reactor, Raleigh, N.C.
Complete loading plus spares

Northern States Power Reactor, Sioux Falls, S. D.
Fuel for boiler critical loading

Penn State Reactor, State College, Pa.
Complete core loading

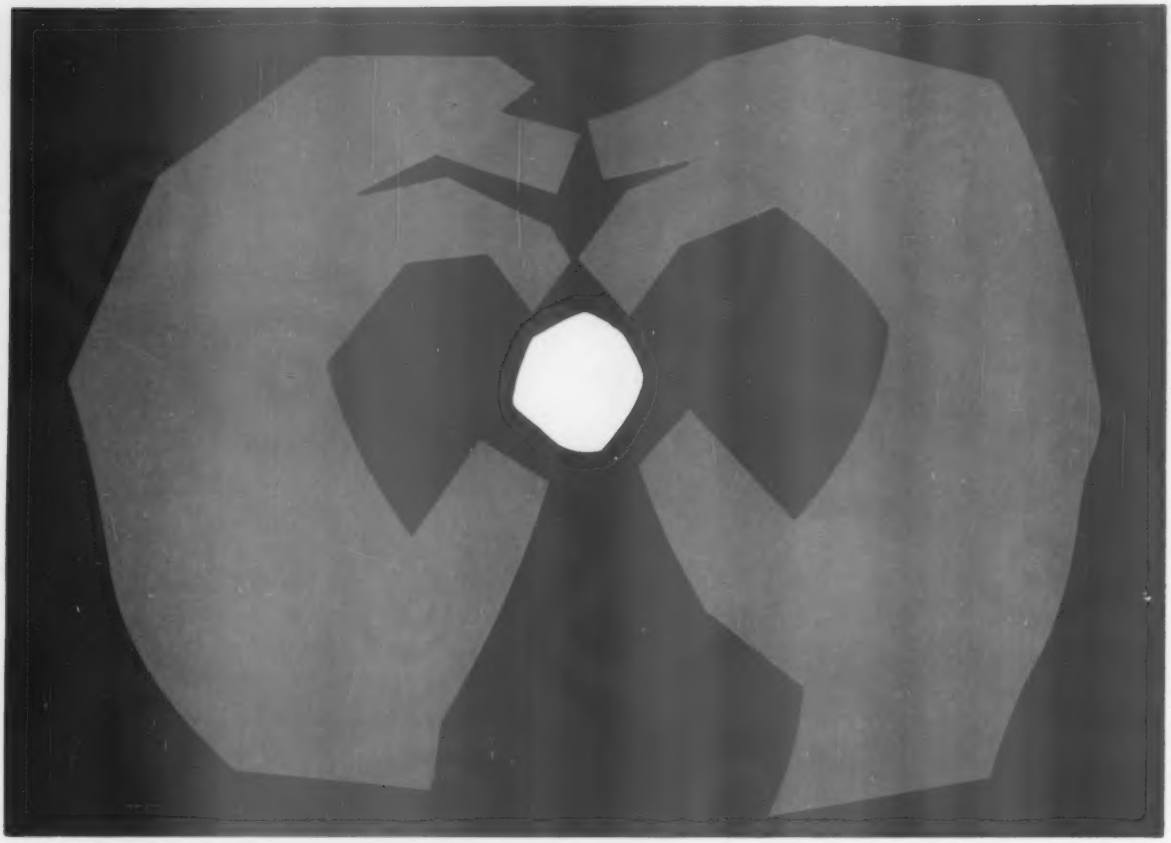
Production Reactors, A.E.C., Savannah River, S. C.
Continuous loadings

Triton Reactor, Saclay, France
Complete core loading plus spares

University of Florida, Gainesville, Fla.
Argonaut type; complete loading plus spares

SYLCOR

SYLVANIA—CORNING NUCLEAR CORP.



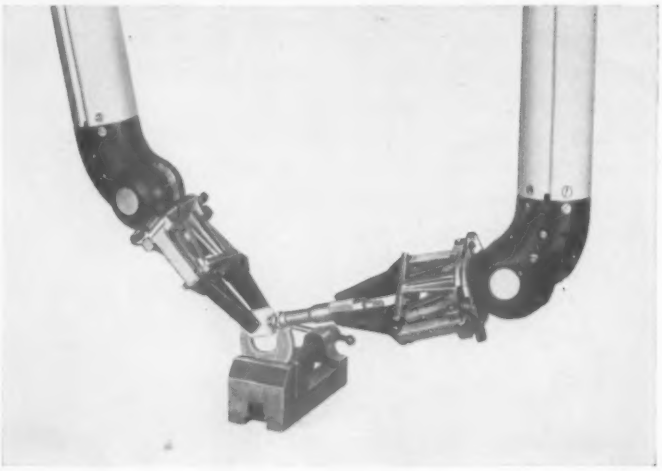
CRL manipulators...

AS OBEDIENT AS YOUR HAND!

Slave ends of CRL Manipulators obey perfectly—duplicate the natural motions of the operators' hands—make operation of the system amazingly simple. An operator becomes perfectly adept with practically no training.

Simplicity of operation is only one of several reasons research and production organizations all over the world specify CRL Manipulators. The system is versatile. Accessories such as special-purpose tongs, load hooks, motion locks, and protective booting allow adaption to a great variety of purposes. A continuous program of improvement . . . uncompromising workmanship . . . and standardized, interchangeable parts provide more reasons why you should consider CRL Manipulators for handling hazardous materials.

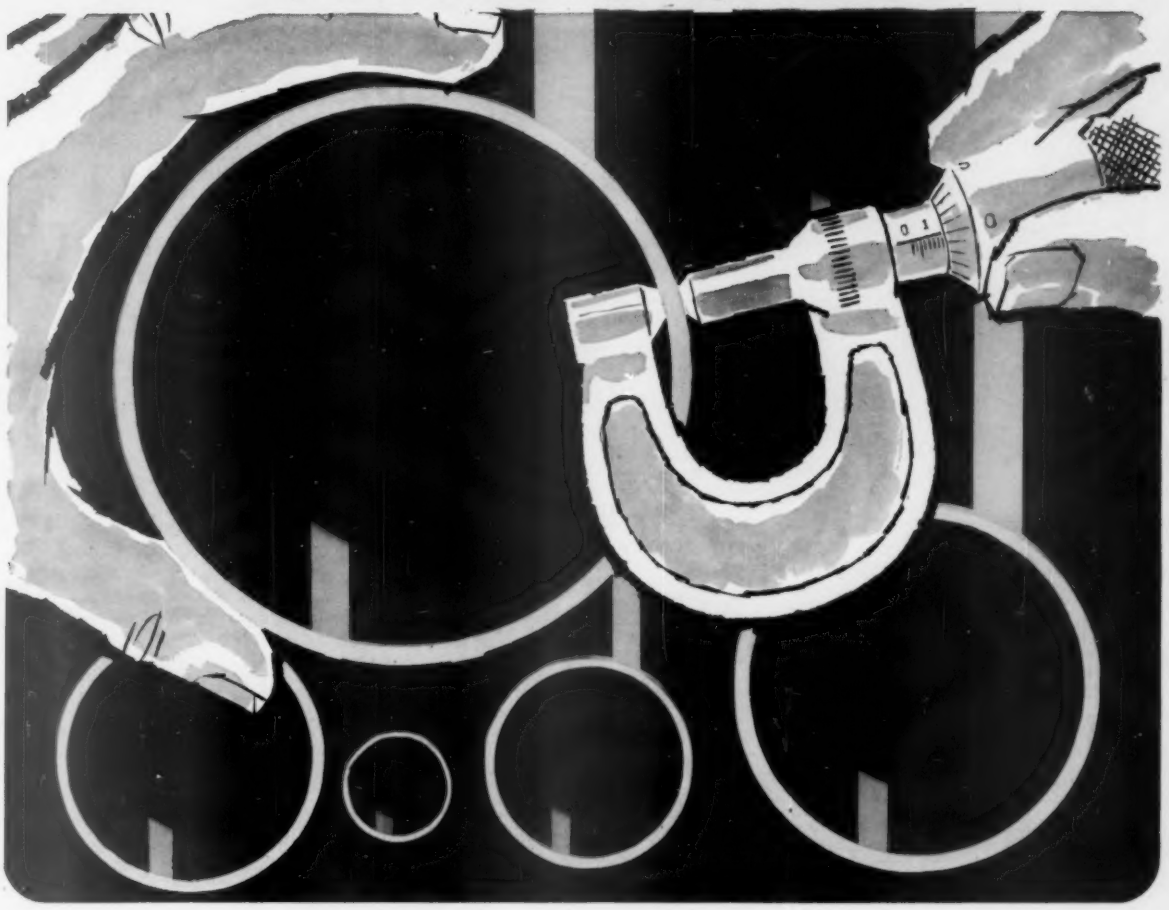
Central Research Laboratories will be glad to advise you on the handling of radioactive materials, explosives, hazardous chemicals, biological materials—in the layout of hot cells—in other research areas, too. For complete information, write CRL today.



Central Research Manipulators from basic Argonne National Laboratory design

Central Research
laboratories, inc.
Red Wing, Minnesota, Dept. 101

Experience *— the added alloy in* ***Allegheny Stainless***



looking for thin walls in big diameters?

A-L now offers a wide range of stainless seamless tubing with walls as thin as .013".

From what other source would you expect to get stainless seamless tubing of 3½" OD with walls as thin as .058" and in the widest range of materials anywhere to fit a broad range of requirements in new products and processes?

Allegheny Stainless Tubing ranges for 3/16" OD to 3½" OD with wall thickness from .013" to .375". Typical of the specials A-L can make are 2½" OD—.032" wall thickness, 3" OD—.042" wall thickness and 3½" OD—.058" wall thickness. All sizes with true circularity, no dents or handling marks.

Stainless seamless tubing is made in all stainless grades including 309, 317, 318, 310, 416 and 446—normally difficult to obtain. For special high-temperature applications, A-L produces tubing in high-strength alloys such as A-286, and in vacuum melted steels and alloys. Also in custom analyses such as low cobalt (.01-.05) grades and with boron additions to standard grades.

A-L also makes composite tubes with bonded combinations of carbon and stainless steels and other metals for unusual corrosion applications in process equipment.

Allegheny Ludlum Tubing is available in small orders in random or cut lengths. Standard grades in stock throughout the country.

Write for your copy of Allegheny Ludlum Stainless Tubing, or call your A-L representative for all the help you need. ***Allegheny Ludlum Steel Corporation, Oliver Building, Pittsburgh 22, Pa. Address Dept.*** *NC-18.*

NEW!
FREE—A-L's new book on stainless tubing. 32-pages of technical data, sizes, grades and suggested applications.

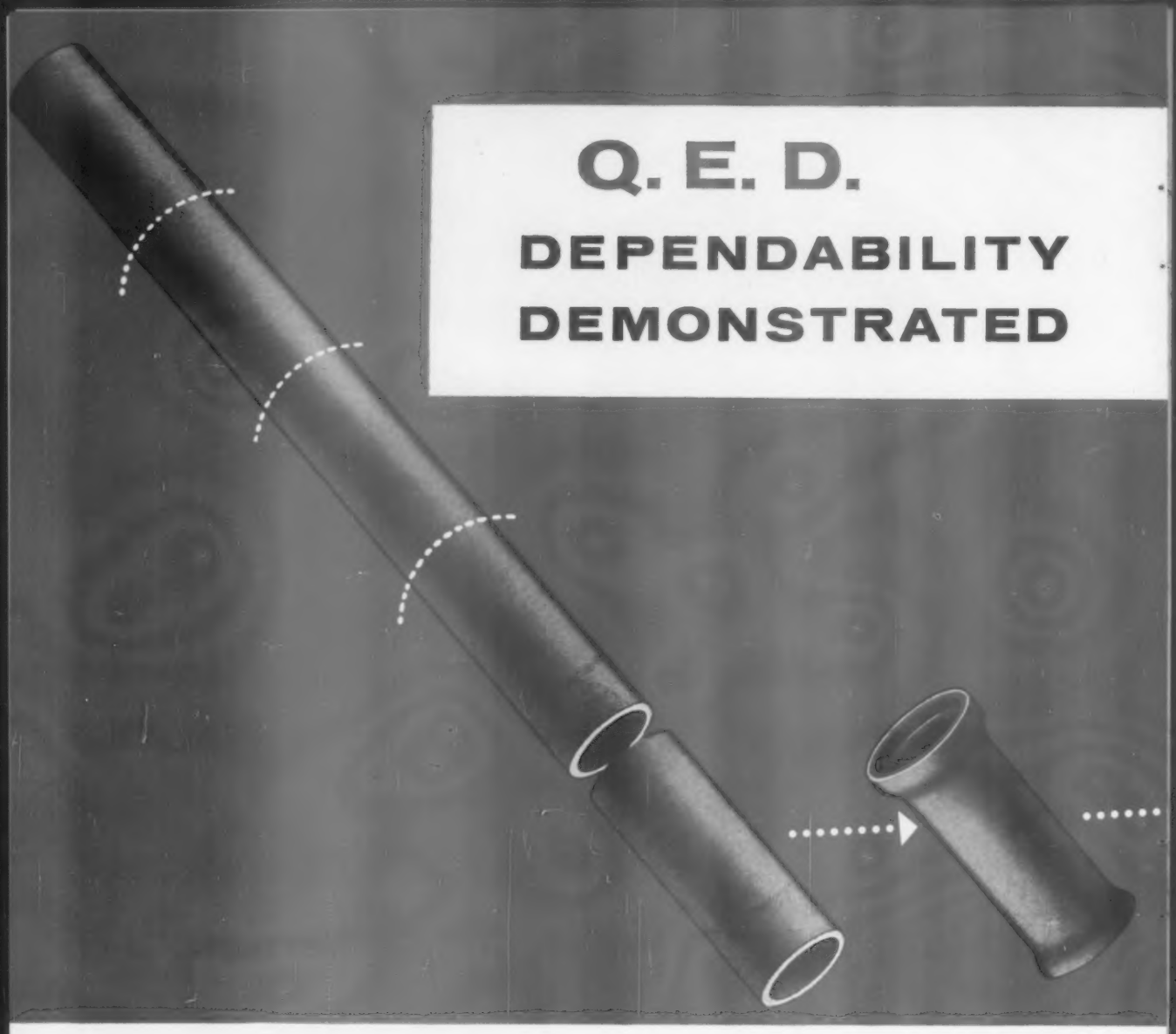
WEW 7838

ALLEGHENY LUDLUM

for warehouse delivery of Allegheny Stainless, call RYERSON

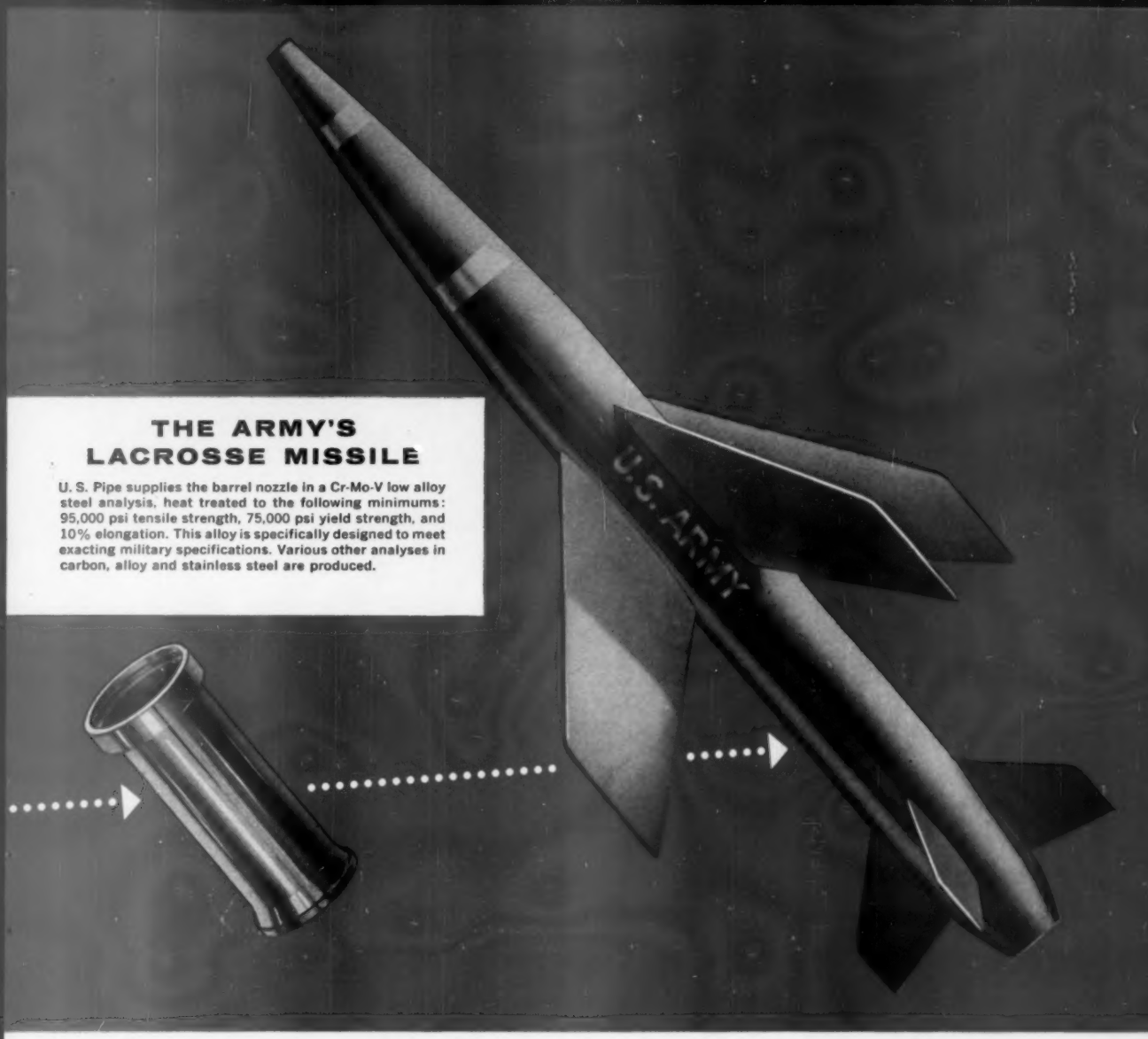
Export distribution: AIRCO INTERNATIONAL

EVERY FORM OF STAINLESS . . . EVERY HELP IN USING IT



Q. E. D.
DEPENDABILITY DEMONSTRATED

Now... basic characteristics of Metal Mold Centrifugal Casting contribute to the reliability of new Lacrosse Missile



THE ARMY'S LACROSSE MISSILE

U. S. Pipe supplies the barrel nozzle in a Cr-Mo-V low alloy steel analysis, heat treated to the following minimums: 95,000 psi tensile strength, 75,000 psi yield strength, and 10% elongation. This alloy is specifically designed to meet exacting military specifications. Various other analyses in carbon, alloy and stainless steel are produced.

Centrifugal casting, a direct production approach to quality, is now finding new and increasingly useful applications in rocketry and missile engineering.

U. S. Pipe, for example, supplies the alloy steel barrel nozzles for the Army's Lacrosse Missile as semi-finished, partially hot-forged lengths. These production pieces are being supplied to The Martin Company, Orlando, Florida — prime contractor for the Lacrosse, and to Parish Pressed Steel, Reading, Pennsylvania — subcontractor to The Martin Company. The contractors then finish machine them for assembly in the propulsion units.

Centrifugal casting offers ordnance design engineers several outstanding advantages:

1. **Versatility.** Many different alloy and stainless steel analyses, sizes and contours can be produced starting with a hollow billet.

2. **Dependability.** Years of experience in producing metal mold centrifugal castings assures high quality and reproducibility.

3. **Economy.** Maximum utilization of the *right* material produced with a minimum of processing to achieve overall efficiency.

Can these basic qualities meet the requirements and lower the cost of your material needs? Write today and outline your particular problem.

Size Range & Composition Flexibility
Outside Diameter—6" to 60" • Wall Thickness—⅜" and up
Length—Up to 25'
Types of Steel Cast, Carbon, Alloy and Stainless—all standard AISI and ACI grades.

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Steel and Tubes Division

STEEL & TUBES U.S. PIPE DIVISION

BURLINGTON, NEW JERSEY

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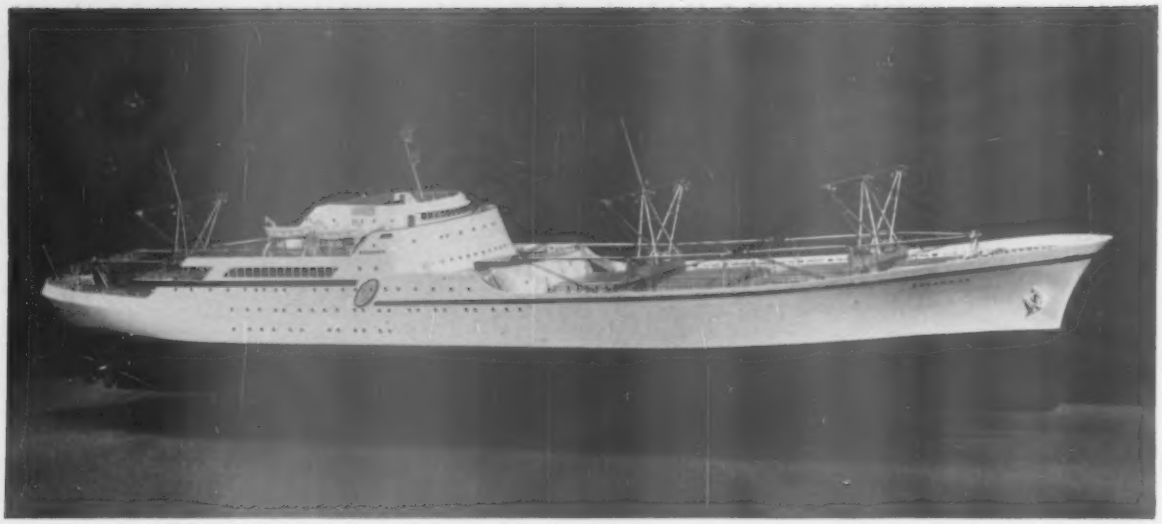


N/S SAVANNAH—from ship model. Will travel 350,000 miles without refueling. Estimated speed: 20.25 knots. Built under joint sponsorship of AEC and U. S. Maritime Administration: George G. Sharp, Inc., naval architects, designers; Babcock & Wilcox, designers, builders of pressurized reactor.

Another "First" for Crane nuclear valves . . . Coolant control on the N/S Savannah!

When the historic *N/S Savannah*—first atomic-powered merchant vessel—goes into service in 1960, flow of the coolant water for the reactor will be controlled by Crane valves.

The choice of Crane valves for controlling fluids in marine reactors began with the *U.S.S. Nautilus.* Since then, virtually all atomic-powered submarines and surface vessels, now in service or under construction, have been equipped with Crane reactor valves.

The same type of safe, dependable Crane valves are used on reactors for nuclear-powered electric generating stations and for experimental reactors at research laboratories.

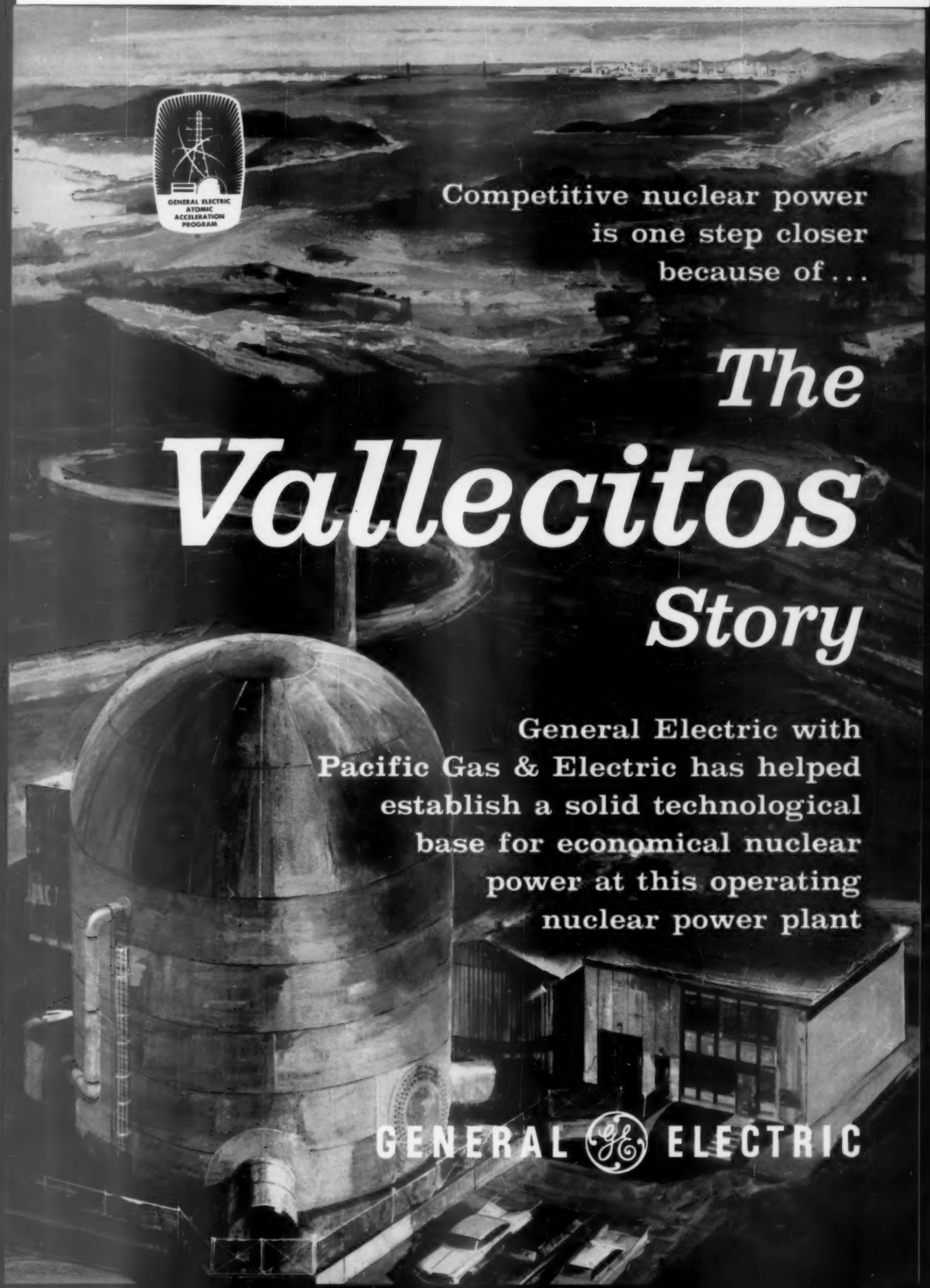
Crane offers you its considerable knowledge and experience in valve design and manufacture, and its modern facilities for designing and testing valves for atomic service. Write today outlining the atomic power project you are developing. A Crane Representative will call promptly.

Four 16" Crane motor-operated gate valves will control the *Savannah's* main coolant lines at 1750 psi; 508 F. Valves are made of Type 304 stainless steel.

CRANE® VALVES & FITTINGS

PIPE • PLUMBING • HEATING • AIR CONDITIONING

Since 1855—Crane Co., General Offices: Chicago 5, Illinois—Branches and Wholesalers Serving All Areas


GENERAL ELECTRIC
ATOMIC
ACCELERATION
PROGRAM
Competitive nuclear power
is one step closer
because of . . .
The
Vallecitos
Story
General Electric with
Pacific Gas & Electric has helped
establish a solid technological
base for economical nuclear
power at this operating
nuclear power plant
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The Vallecitos Story: *helped establish*

POWER OPERATION and experimentation provide valuable data. Operation at 900 to 1000 psi at all power outputs up to 30,000 kw(t) has been stable. Reactor responds quickly to load changes. Plant maintenance is simple; low activity levels permit direct-contact maintenance. Refueling has been accomplished in less than a day of shutdown including time required for system thermal cooling and reheat to 540 degrees F.

Vallecitos Boiling Water Reactor experience shows the way to greater technological advances... brings competitive nuclear power closer

VBWR has performed both as a dependable power producer and as an outstanding fuel and component test facility.

These advantages of boiling water reactors for utility service have been demonstrated:

Ease of Operation—Start-up of VBWR from cold conditions to full-power takes only five hours. Reactor shutdown, rearrangement or replacement of fuel bundles, and restart takes only 24 hours. High-power, high-pressure operation has been stable. Refueling is fast and easily accomplished.

Stability—VBWR has been stable in operation at 900 to 1000 psi at all power outputs up to 30,000 kw(t).

Rapid Response to Load Change—Load changes from 200 to 5,000 kw in 15 seconds are performed with resultant change of only 30 psi in reactor pressure.

Reliability of Operation—Although primarily a research facility, VBWR has logged more than 20 million electrical kilowatt hours (over 106 million thermal kw-hr) since first operation in October 1957. Plant availability during commercial power service has been extremely high, averaging over 95% in a typical period. Unavailability resulted largely from time required to conduct experimental programs. Originally rated 20,000 kw(t), the reactor has operated at 30,000 kw(t) and is expected to operate satisfactorily at its presently licensed rating of 50,000 kw(t).

Ease of Maintenance—Low radioactivity levels permit direct-contact maintenance of turbine and auxiliaries using normal procedures. Radiation poses no problem to reactor maintenance.

SIGNIFICANT TEST CONTRIBUTIONS

Extensive programs to prove oxide fuels for commercial service are in progress. Fuel elements have been tested under more severe irradiation than actual power plant operation will involve.

Plant operation experiments have included: studies of forced-circulation and dual-cycle operation; evaluation of in-core monitors and rupture detectors; determination of stability; studies of coolant chemistry, corrosion effects, and the dynamics of boiling; and evaluation of decontamination methods.

VBWR experience has added significantly to the technology of the boiling water reactor type . . . technology that is exploitable by intensive development via a clearly predictable path to economical nuclear power plants.

Progress Is Our Most Important Product

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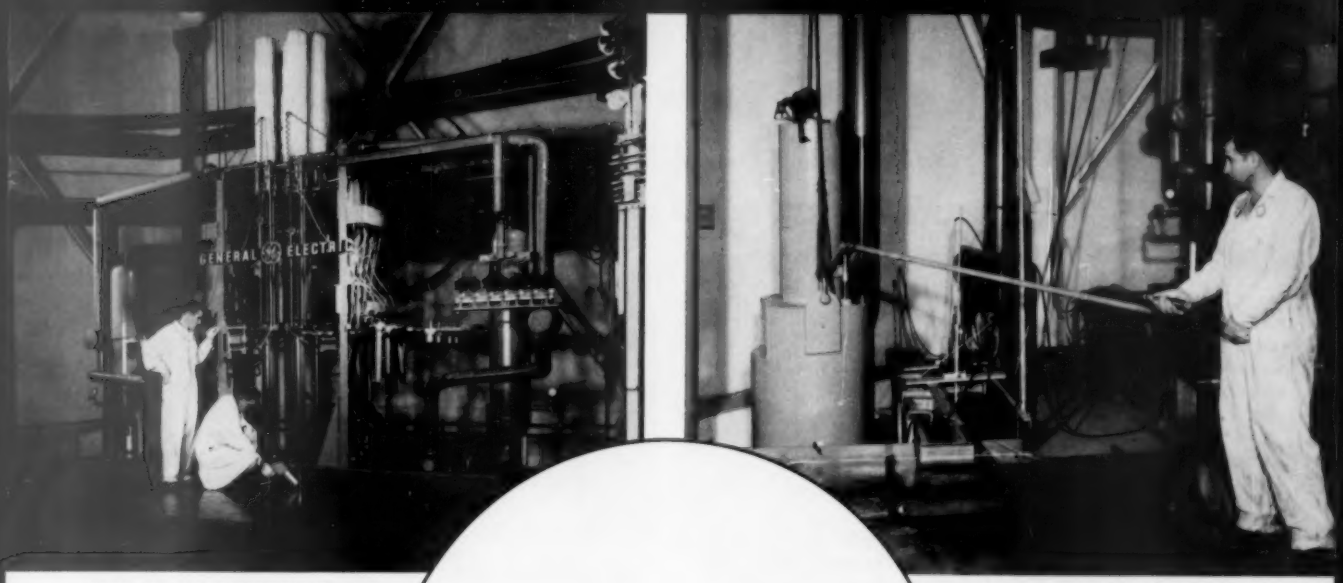
solid technological base

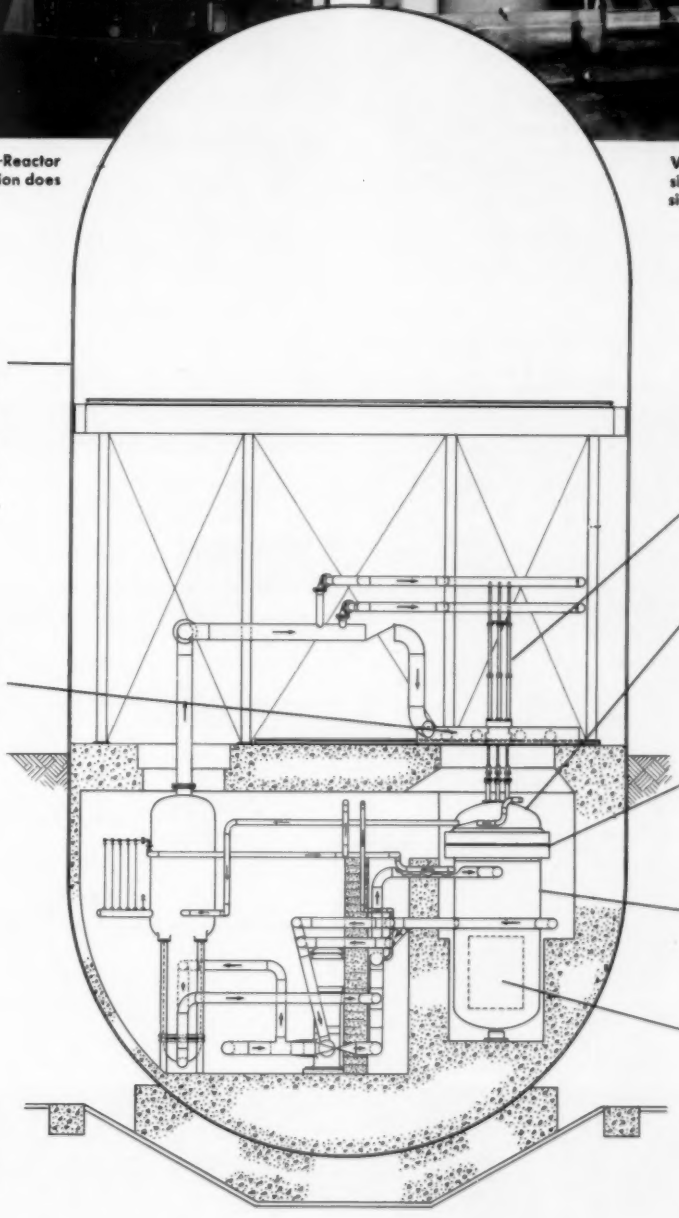


EASE OF MAINTENANCE—Reactor maintenance is simple. Radiation does not pose any problems.

VALUE IN RESEARCH—VBWR design permits experiments in fuel design, rupture, long-term performance.

REACTOR HOUSING is 48-foot diameter, vapor-tight steel enclosure, 100 feet high. Lower area contains reactor and associated equipment including secondary steam generator for dual-cycle loop.

BIOLOGICAL SHIELD is 18-inch-thick steel shield weighing 80 tons. Mounted on wheels and rails, shield separates into three parts for refueling or head removal.



REACTOR CONTROL RODS are electropneumatically driven. Seven rods control core reactivity.

REFUELING PORTS are located in the top head. Four 12-inch ports allow refueling of the core without removal of the head.

HEAD OPENING is full diameter of the vessel so the entire core and its supports may be removed and replaced if desired.

PRESSURE VESSEL has 7-foot diameter, is 20 feet high, fully lined with stainless steel.

REACTOR CORE includes 30 developmental prototype elements of various designs being tested for power plant service.

VBWR is a light-water-moderated-and-cooled boiling water reactor producing 1000 psi steam which is used directly in a 5000-kw turbine.

after Vallecitos...acceleration

General Electric's Atomic Acceleration Program can broaden solid technological base, speed competitive nuclear power

Acceleration to competitive nuclear power is necessary for national security and world leadership, technological and idealogical. General Electric's Atomic Acceleration Program —a major effort in developing boiling water reactors— promises the fastest realization of that goal, at minimum cost with least technological and financial risk. The program complements government and industry objectives. Concurrently, General Electric will continue to investigate other promising reactor types.

VBWR is making important contributions in the First Generation Phase of the Program. Immediate implementation of the Developmental Phase is required, with these reactors needed to improve and test specific combinations of boiling reactor technology:

NCB-2 The **NATURAL-CIRCULATION BOILER** reactor, rated at 50 mw(e) has been committed by P G & E for the Humboldt Bay station and will stress extreme simplification and lowered costs.

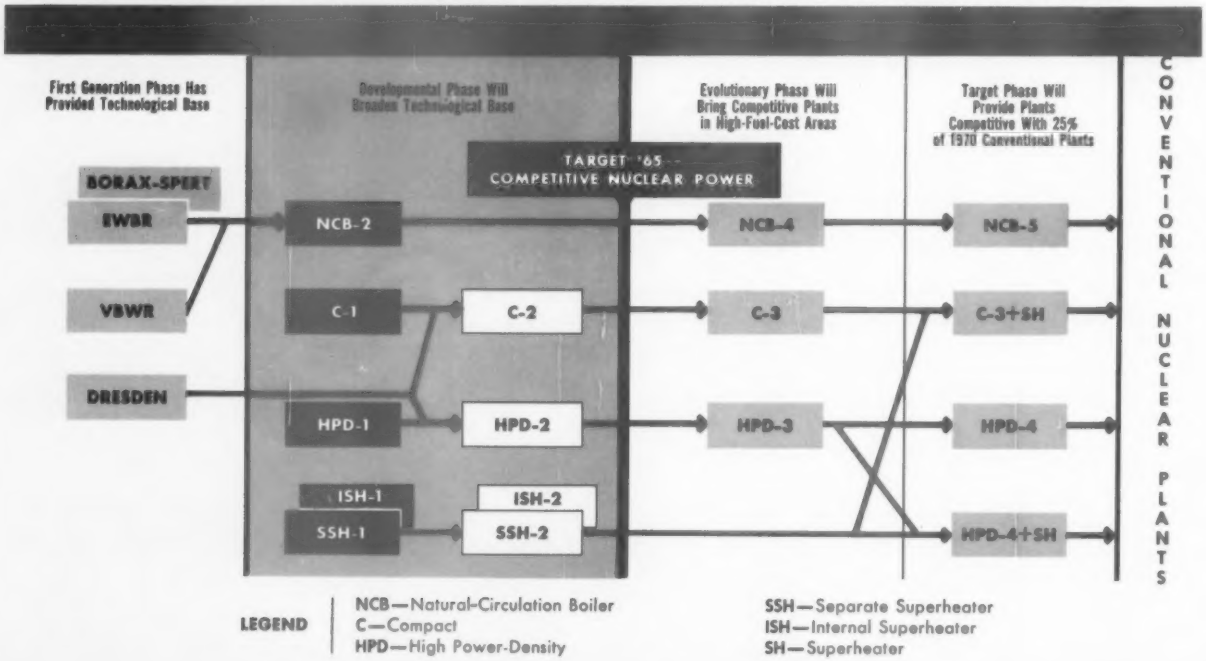
C-1 A **COMPACT** reactor, rated at 10–25 mw(e), is required to develop optimum design and construction simplicity for forced-circulation plants.

HPD-1 A **HIGH POWER-DENSITY** reactor, rated at 25–50 mw(e), is required to test the limits of power density and provide full-scale proving of high-power-density fuel.

SSH-1 or ISH-1 A **SEPARATE SUPERHEATER** or **INTERNAL SUPERHEATER,** rated at 10–100 mw(e), is required to evaluate operation and maintenance characteristics, extend nuclear superheat technology.

FOR INFORMATION on participation in this program, contact your nearest General Electric Apparatus Sales Office or write: Atomic Power Equipment Department, 2151 South First Street, San Jose, California. Publications GED-3750, "How to Implement Nuclear Power Acceleration" and GER-1574, "Operation Sunrise," provide more detailed discussion of the program, are obtainable by writing Section 192–13, General Electric Co., Schenectady 5, N. Y.

THE COMPLETE ACCELERATION PLAN FOR COMPETITIVE NUCLEAR POWER



Progress Is Our Most Important Product

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call on Ebasco's nuclear engineering services

Ebasco's increasing activities in nuclear engineering place at your disposal a wide range of specialized services in this growing field. Augmenting Ebasco's competence in this field is a 50-year reputation for uncompromising quality in diversified engineering and construction work. This combination offers you sound assurance of practical and economical results in the application of atomic energy.

Ebasco performs the following nuclear engineering services for clients:

- ★ Reactor Systems Evaluations
- ★ Design of Nuclear Plants
- ★ Construction of Nuclear Plants
- ★ Hazards Analyses
- ★ Start-Up and Testing of Plants
- ★ Training of Operating Staff
- ★ Engineering and Economic Investigations
- ★ Research and Development Assistance
- ★ Nuclear Investment Consultation
- ★ Coordination with Government Agencies

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Consulting Engineering • Design & Construction • Facilities Planning • Financial & Business Studies • Industrial Relations
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Neither stargazer nor mystic, this K & M technician can nevertheless see into the future. His crystal ball is a small mass of radioactive Iridium; his fortune-telling cards, gamma-ray pictures of critical valve assemblies. With these pictures he searches out the kind of subtle flaws and tiny imperfections that could become trouble spots at some future time. And so he is able to predict and prevent in-service failures and malfunctions.

Radiographic inspection is just one way in which K & M works to insure a long and healthy service life for its products. K & M's in-plant quality control facilities range from a contour comparator, for precision checking of small parts, to a 4000-gpm flow test loop, where sample valves from the production line are tested for on-stream performance. Micrometer and calipers play an important part, too, for each K & M valve is subjected to more than eight hundred dimension check-outs before it reaches the shipping crate. It's either perfect, or "no go."

K & M's meticulous standards of quality control are neither myth nor magic . . . just good business — for us, and for you.

For a more detailed view of our plant and production practices, send for the well-illustrated, informative brochure, "This Is K & M."

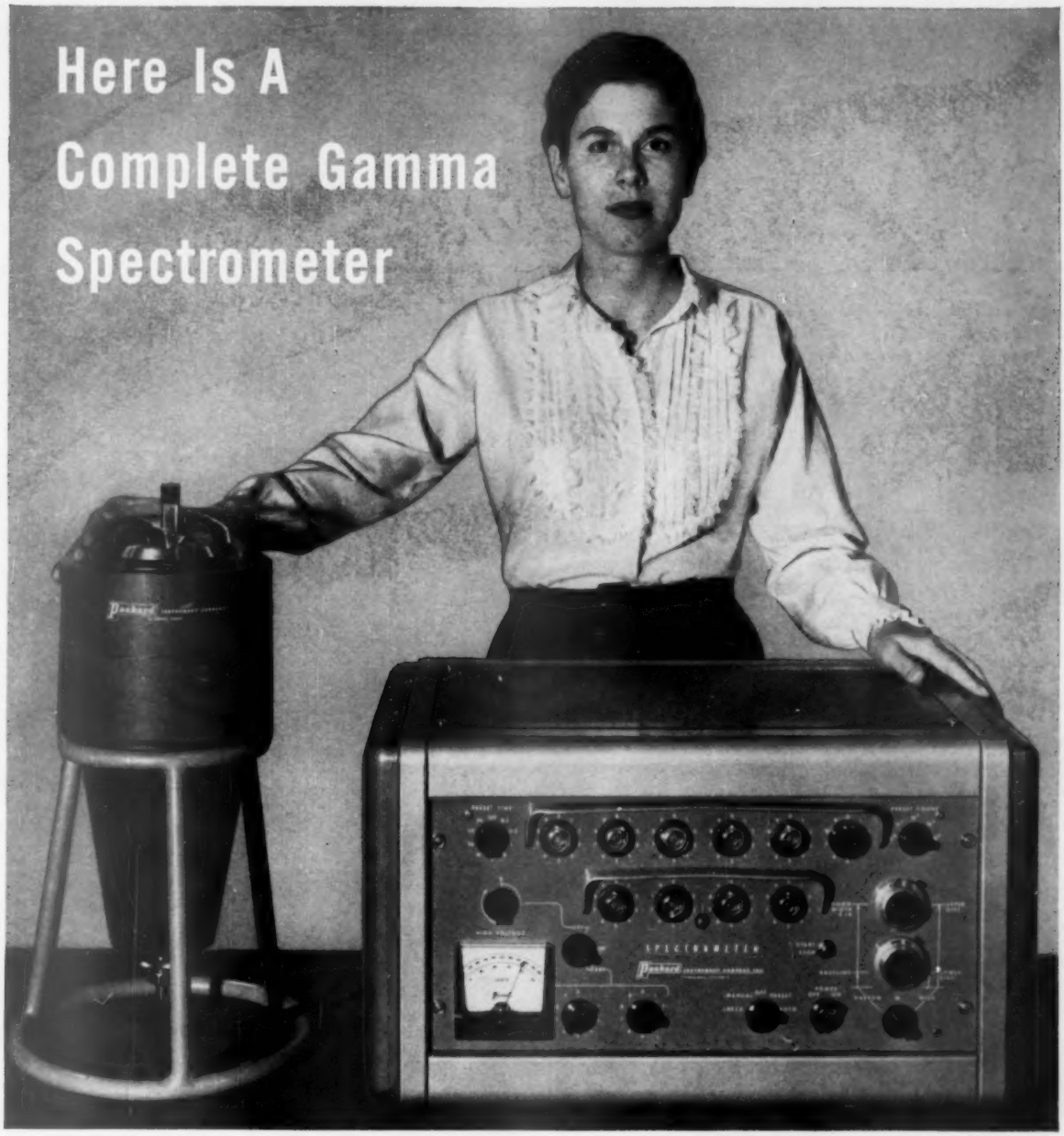
K&M

diaphragm control valves

KIELEY & MUELLER, INCORPORATED

Our 79th Year

Oldest Pressure and Level Control Valve Manufacturer
64 Genung Street, Middletown, New York



This transistorized spectrometer is by far the smallest and most compact available—yet it has more important and unique features than any other on the market today. Furthermore, it can be used directly with the Packard Auto-Gamma Sample Changer for completely automatic counting of test tube samples.

Write for Complete Information. Request Bulletin 400.

Packard *Instrument Company, Inc.*

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From America's largest integrated

Zirconium is now available from Mallory-Sharon in the form of rounds, bars and billets, wire, tubing, strip, foil, sheet and plate. Quality and properties are carefully controlled at every stage of production.

producer of Special Metals...

1,000,000 LBS. OF ZIRCONIUM

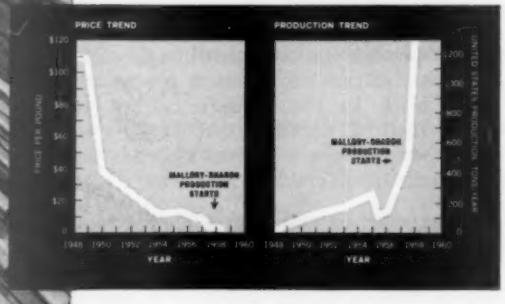
to be available for commercial use in '59

A few short years ago zirconium was an expensive rarity. Today, it is readily available for commercial use. And Mallory-Sharon has led the way in this rapid development.

Prices of zirconium mill products have consistently been reduced . . . due to Mallory-Sharon's large scale, low cost chunklet production methods and integrated melting and rolling facilities. In nuclear reactor applications, zirconium now offers important economic advantages over other materials.

With 1,000,000 lbs. of zirconium available from Mallory-Sharon for commercial use in 1959, users benefit from both ready availability and reduced costs.

Write us for technical information or engineering assistance on specific applications.



Production up... Prices down

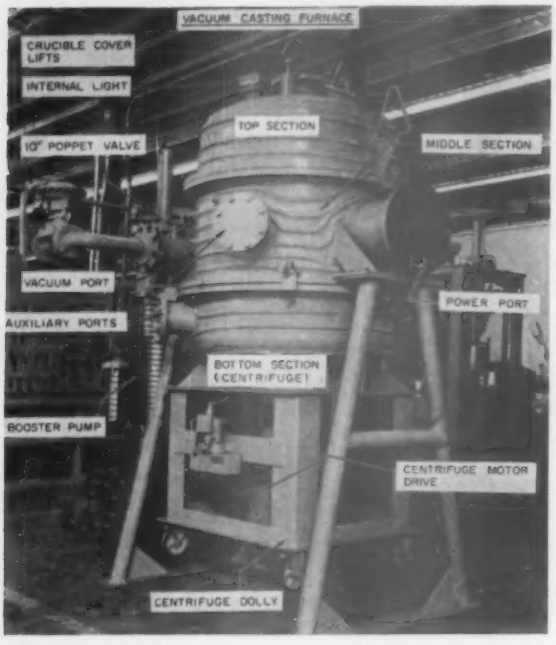
Mallory-Sharon's modern, efficient chunklet plant at Ashtabula, Ohio, is now in full production. Using a new, lower-cost sodium-reduction method, it has been possible to sharply reduce prices of zirconium chunklets. These reductions are directly reflected in lower prices for Mallory-Sharon mill products.

MALLORY SHARON

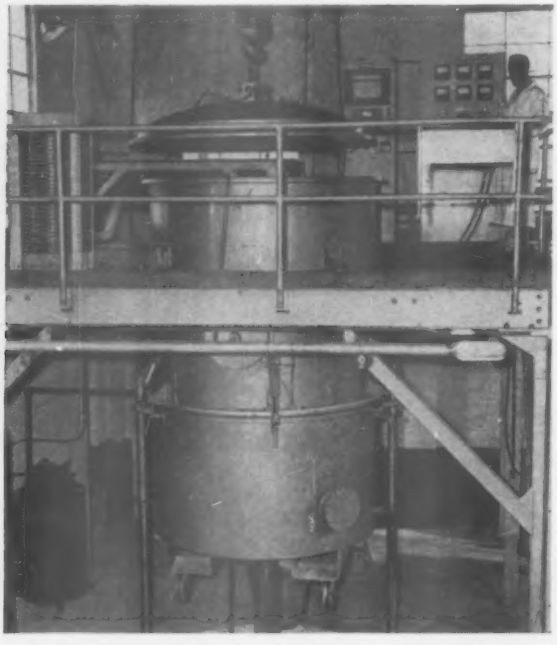
MALLORY-SHARON METALS CORPORATION · NILES, OHIO

Integrated producer of Titanium · Zirconium · Special Metals

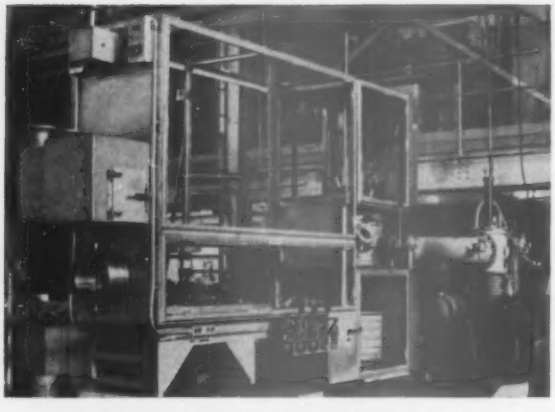
RADIOACTIVE MATERIAL HANDLING investigations are safely carried out with this Stokes prototype vacuum furnace. It is remotely operated by manipulators and other external controls. This installation represents another specific requirement met through Stokes flexibility.



URANIUM MELTING ON A PRODUCTION BASIS is accomplished by this Stokes induction melting furnace. Designed for safety and convenience, the furnace is serviced from the top and features a removable bottom section to facilitate handling of poured materials. It is typical of Stokes inherent flexibility.



nuclear flexibility



PLUTONIUM MELTING AND CASTING will soon be easily accomplished by this Stokes vacuum furnace being assembled for shipment to customer's plant. The entire system will be enclosed within a vacuum dry box for "clean handling" and operation: another example of Stokes design concept flexibility.

Metallurgical investigations are leading to new, practical applications: plutonium melting and casting, uranium melting on a production basis and new methods of handling radioactive materials . . . are just a few. At Stokes, extensive design experience and manufacturing facilities work hand-in-hand to make these developments possible. Stokes pioneered in the application of vacuum metallurgy to the nuclear field. In the modern Stokes laboratory, vacuum melting, casting, heat-treating and pelletizing experiments are providing new methods of overcoming traditional bottlenecks.

Stokes experience and aggressive developments in the field of nucleonics can go to work for you. Whatever your requirements, the inherent flexibility of Stokes design concepts is assurance that your stringent needs can be met. Why not investigate further by writing or calling Stokes today.

Vacuum Metallurgical Division
F. J. STOKES CORPORATION
5500 Tabor Road, Philadelphia 20, Pa.

STOKES

For the first time... Multiplier Phototubes

with S-20 response!

You are looking at the first commercial multiplier phototubes having S-20 spectral response and featuring a revolutionary new type of photocathode.

The greatest advancement in the field of photoemission in 20 years, this new type of photocathode offers three major steps ahead in multiplier-phototube performance: (1) It has the highest red sensitivity of any type of photocathode known; (2) It provides 40 per cent higher overall sensitivity than blue-sensitive photocathodes used in tubes having S-11 response and also permits a ten-fold improvement in equivalent noise input; (3) It has low thermionic dark current, *plus high conductivity—even at temperature as low as that of liquid air!*

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For free technical information on RCA-7265 and -7326, as well as Catalog CRPD-105A on RCA Photosensitive Devices and Cathode-Ray Tubes—covering RCA's multiplier phototubes—write RCA Commercial Engineering, Section F-31-Q, Harrison, N. J.

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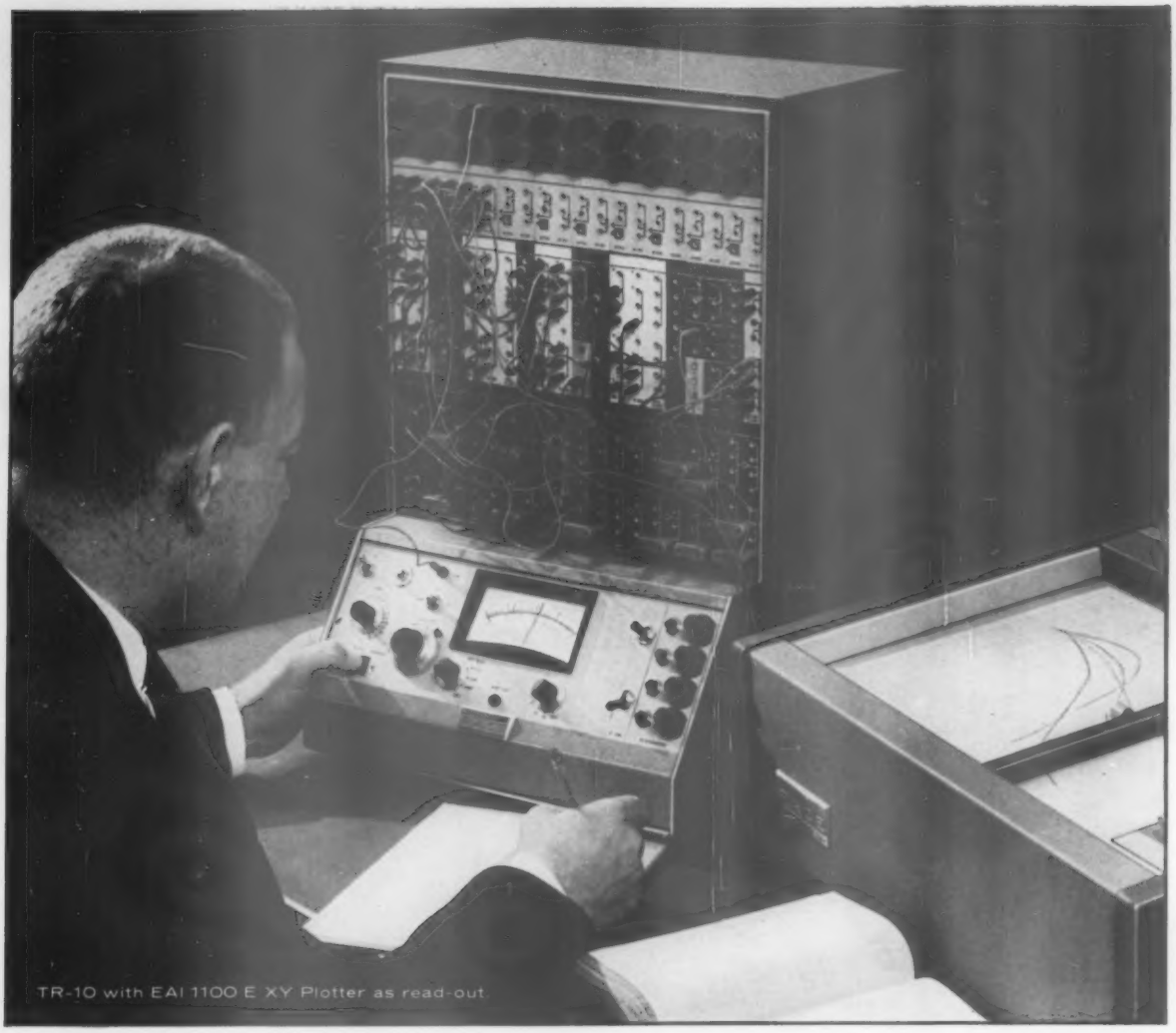

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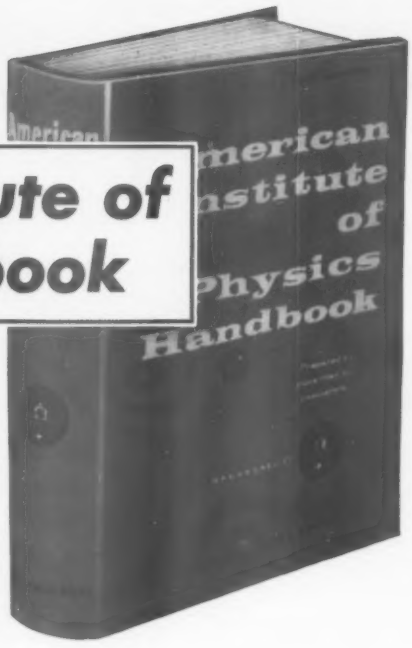

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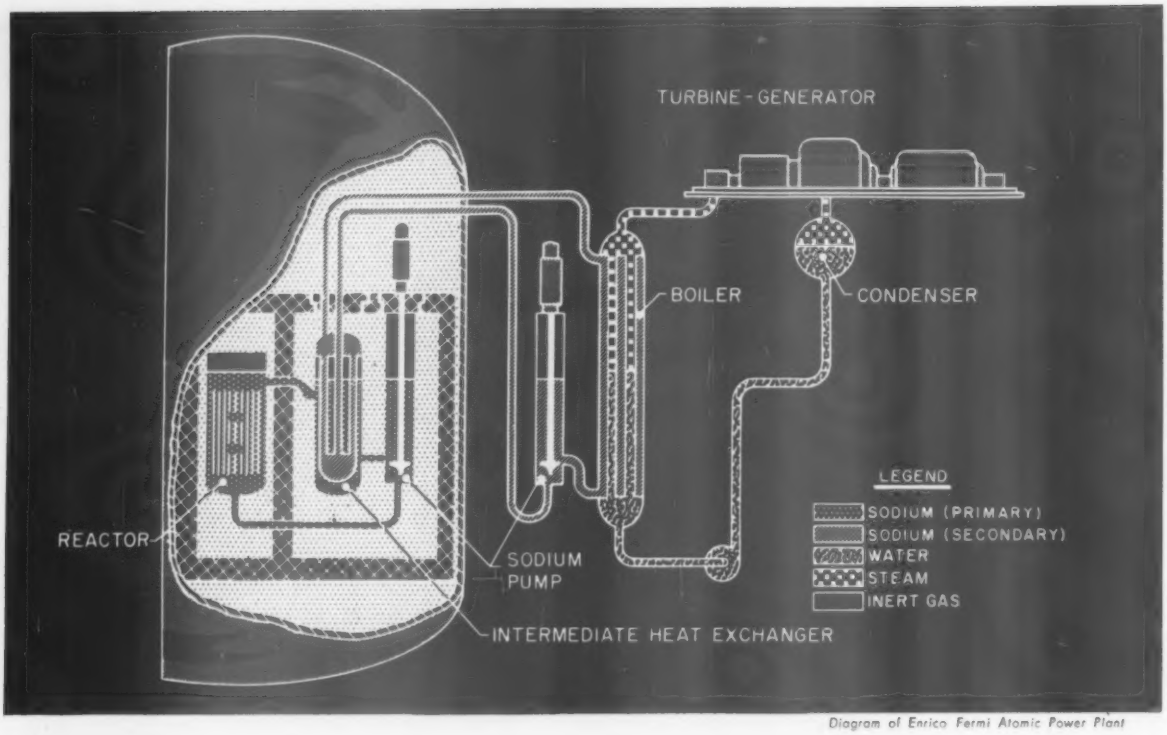

Diagram of Enrico Fermi Atomic Power Plant

SODIUM-COOLED FERMI REACTOR WILL GIVE FAST BREEDER DESIGN FIRST FULL-SCALE PLANT TEST

Enrico Fermi Reactor, now under construction on Lake Erie near Monroe, Michigan, is the first large-scale power plant of its type, will demonstrate feasibility of fast breeders for electric power production.

The fundamental advantage inherent in fast breeder reactors is that they produce more nuclear fuel than they consume. Consequently, this type of reactor will conserve and add to the nation's reserves of nuclear fuels rather than deplete those resources.

The Fermi Reactor, now being built by Power Reactor Development Co. (PRDC), is scheduled to go critical late next year. It is designed to generate 300,000 thermal KW, which will be converted to 100,000 electrical KW through a conventional steam cycle. Detroit Edison will build and own the steam turbine-generator, which it will operate on steam purchased from PRDC.

Liquid metallic sodium will transfer the heat generated in a tandem heat-exchange system. In the primary loop, sodium will enter the reactor at 550°F, leave it at 800°F. This heat will be transferred to secondary loops which will enter the steam generator at 750°F, leave it at 500°F. Steam will be produced at 740°F and 600 psia.

Sodium meets the two major requirements for a fast breeder coolant: it does not moderate neutrons and it has outstanding heat-transfer properties. In addition, sodium's high boiling point permits high thermal efficiency, while its melting point is low enough so that ordinary structural materials can be used. Other advantages of sodium: it is easy to pump, and is low in cost.

The U.S.I. brochure, "Handling Metallic Sodium on a Plant Scale", has further information on sodium. Write for it, and, if you have special questions, call us for technical service.

FIVE OTHER SODIUM-COOLED REACTORS

- Experimental Breeder Reactor-1 (EBR-1), NRTS, Arco, Idaho—fast breeder, sodium-potassium cooled —15,000 KW (e) (operational)
- Sodium Reactor Experiment (SRE) Santa Susana, Calif. — graphite-moderated—6,500 KW (e) (operational)
- Experimental Breeder Reactor-2 (EBR-2) NRTS, Arco, Idaho—fast breeder—20,000 KW (e) (under construction — slated for 1960 operation)
- Consumers Public Power District, Hallam, Neb.—graphite-moderated —75,000 KW (e) (under construction—slated for 1962 operation)
- Chugach Electrical Association, Anchorage, Alaska—heavy water-moderated — 10,000 KW (e) (evaluation stage)

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In actual operation the Serviscaler scales data on five decade glow tubes with a maximum capacity of 99,999 counts. And high voltage is continuously adjustable between 600 and 1600 volts.

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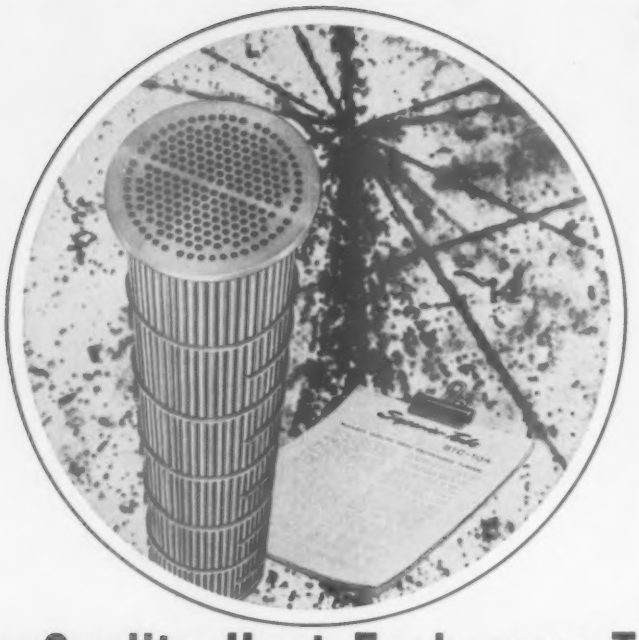

Nuclear-Quality Heat Exchanger Tubing Made to Superior's Specification STC-104

Superior has established a new quality-level for heat exchanger tubing to answer the demand for the high degree of precision required in the nuclear field. Superior's new Specification STC-104 sets new high standards of manufacture for nuclear-quality heat exchanger tubing in five grades of stainless steel in a range of sizes up to 1⅛ in. OD. Here are some of the requirements it stipulates:

MATERIALS. Nuclear-quality heat exchanger tubing shall be produced in AISI types 304, 304L, 316, 347, 348 and other austenitic grades as required.

RAW STOCK QUALITY. Shall be selected from high-quality tubing hollows. A statistical sampling of the tube hollows shall be made to select stock with the most uniform dimensions.

IN-PROCESS INSPECTION. Inspectors shall check work in process for general surface appearance, size and handling procedures to prevent damage to the tubing.

FINISH QUALITY. OD and wall thicknesses shall be held within commercial tolerances unless otherwise specified. Ovality shall be within 3% of the theoretical average OD. Commercial straightness (1 part in 600) shall apply. Dimensional checks shall be made on a 100% basis. Outside surfaces shall be 100% visually inspected.

MECHANICAL PROPERTIES. Shall conform with ranges established by Superior's Metallurgical Department. Typical of the properties given in STC-104 are those shown here for Type 348:

Ultimate Strength (psi)	Yield Strength (psi)	% Elongation in 2 in.
75,000-105,000	30,000-57,000	37 min.

CLEANLINESS. Inside and outside surfaces shall be bright and free from discoloration, grease, dirt, metal shavings, metal particles, and other foreign matter.

FLARING & FLATTENING. Tubing shall be flared with a tool having a 60-degree included angle without cracking or showing flaws. Tubing shall be flattened cold between parallel plates to a distance of three times the wall thickness without cracking or breaking.

SURFACE ROUGHNESS. When specified, surface roughness shall not exceed 63 microinches on either the inside or outside surfaces.

NONDESTRUCTIVE TESTING. A dye penetrant test will be made on a statistical sampling basis. No imperfections greater than 10% of the wall thickness shall be permitted. On tubing with .040 in. wall and heavier, no defects shall exceed .004 in. Tubing which is Eddy Current tested shall be within the above maximum defect level. Mill consultation is required for ultrasonic testing. When specified, it will be done to a .004 in. defect level for tubing ½ in. OD or larger x .040 in. wall and heavier. Hydrostatic testing shall be performed on all tubing.

For full particulars on Nuclear-Quality Heat Exchanger Tubing, write for a copy of Superior Specification STC-104 and also of Data Memorandum #20. Superior Tube Company, 2027 Germantown Ave., Norristown, Pa.

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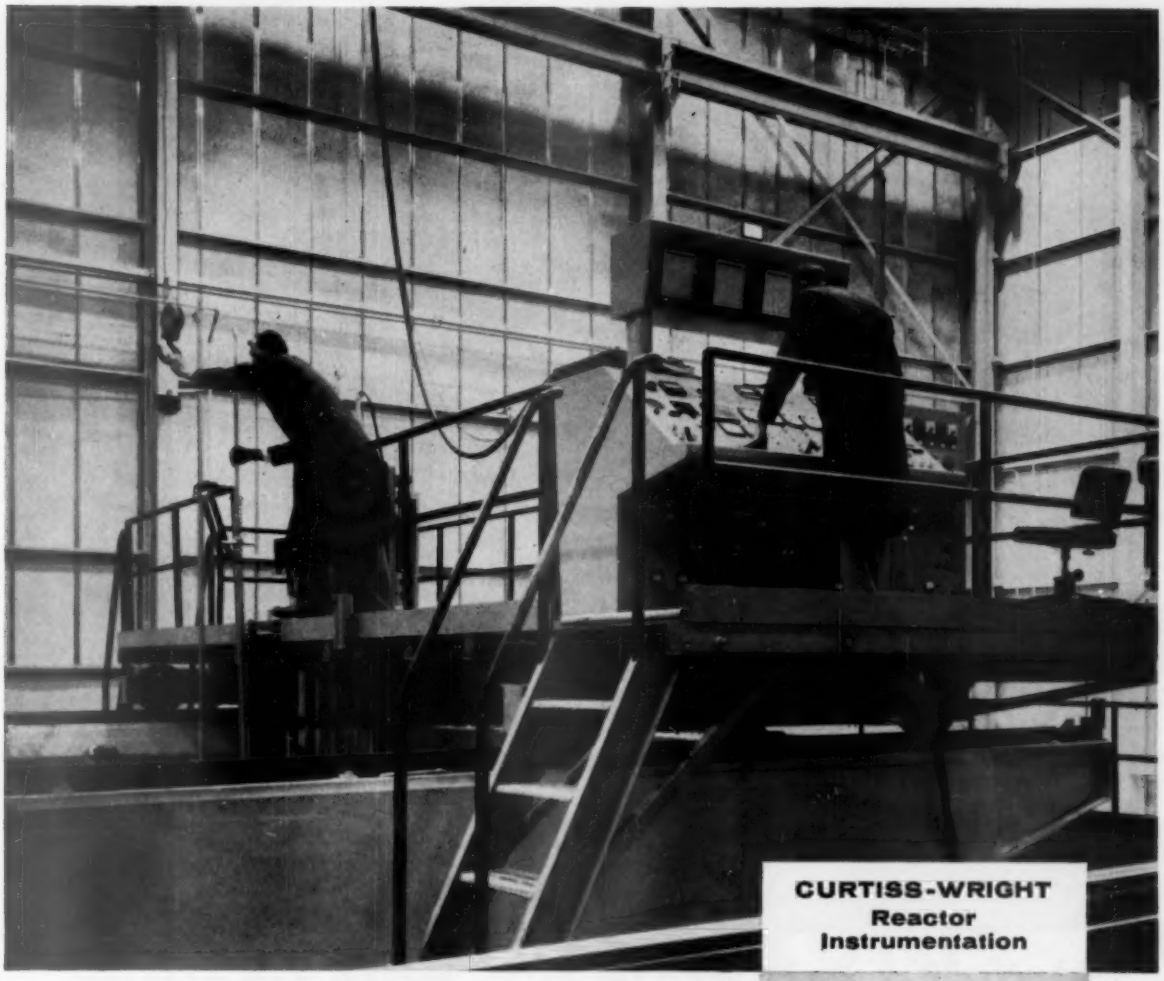

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For further information, write: Director of Nuclear Sales, Curtiss-Wright Corporation, Quehanna, Pennsylvania.

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Engineers designing the 25-Bev Alternating Gradient Synchrotron now being installed at Brookhaven National Laboratory faced a problem much like this when they devised the ½-mile-long circular vacuum cavity in which protons are accelerated to speeds approximately 99.9% that of light.

Ideally, to minimize flux variations and eddy current and hysteresis losses, the vacuum cavity's envelope should have been air. Practically, the elliptical vacuum chamber was formed of Inconel "X"* age-hardenable nickel-chromium alloy.

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Inconel "X" alloy . . . from an electrical and magnetic standpoint . . . behaves almost like air. It is a poor host to eddy currents and its permeability is less than 1.005. What's more, Inconel "X" alloy has low vapor pressure, good degassing characteristics and freedom from porosity. All are important in establishing a vacuum of the high order called for in this equipment.

The electrical and magnetic characteristics of Inconel "X" alloy, coupled with its high strength and good fabricating properties, have led to the use of this Inco Nickel Alloy in a number of advanced devices. Among them is the "canned pump" (motor and pump combined in one housing) where the metal sheathes stator and rotor to protect them from the pumped fluid. The excellent resistance of the alloy to high temperatures and oxidizing conditions puts it in a class by itself for such applications as the skin of the X-15 . . . first manned vehicle for space probes.

If you have an equipment problem involving the need for materials with special strength, heat- or corrosion-resistance or electrical properties, write us. We'll be glad to tell you about the newer alloys that have been developed specifically to handle such conditions.

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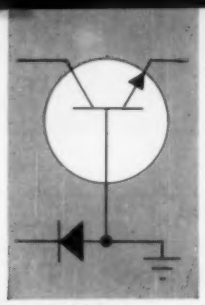

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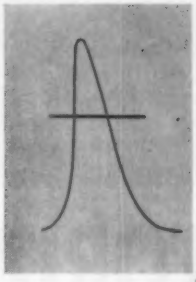

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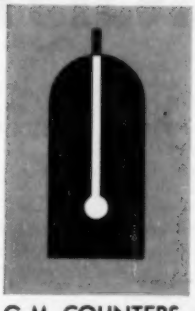


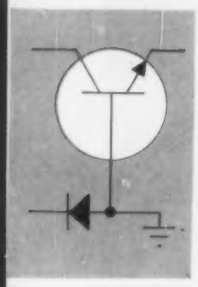
G-M COUNTERS p. 86

A SPECIAL REPORT:

NUCLEONIC INSTRUMENTATION

The demands on nucleonic instrumentation are growing steadily—high-intensity pulsed accelerators require ever shorter resolving times, world-wide sampling programs need automated counting systems and nuclear power stations require ever more reliable monitoring gear. The designers who will attempt to satisfy those demands and the users who are responsible for it have a common need for information on the state of the instrumentation art. As part of our continuing program of trying to fill that informational need we present this 32-page report on nucleonic instrumentation. In it we have stressed certain aspects of the subject that seem to have been most in need of review treatment—the use of transistors, pulse-amplitude discriminators, scalers, commercially available photomultipliers and halogen-quenched G-M counters.

—The Editors



Switching and sorting circuits already put transistors to good use. Improved elements plus design ingenuity will allow amplifiers and power supplies to follow suit

TRANSISTORIZATION

By FRED S. GOULDING, *Atomic Energy of Canada, Ltd., Chalk River, Ontario, Canada*

TRANSISTORS and semiconductor diodes, compared with vacuum tubes in nucleonic instruments, offer the advantages of increased reliability, smaller size and cooler operation. These elements are already replacing tubes in all trigger and switching circuits in the field; recently developed transistors open the way for transistorization of the remaining kinds of circuits basic to radiation detection systems (i.e., pulse amplifiers, d-c amplifiers and power supplies).

Junction transistors seem particularly well suited for nucleonic instruments. The environmental conditions are usually quite acceptable for germanium transistors (where operation is to be at moderately high temperatures, silicon transistors can be used). Because the great majority of instruments operate in low radiation fields, the radiation sensitivity (*1–5*) of transistors is not a problem.

Although no one questions the high reliability of transistors operating under these almost ideal conditions, actual comparisons with vacuum-tube reliability are difficult to make owing to the wide variations in life between circuits that have different functions. The average life of high-quality computer tubes might range from 10^4 to 2×10^5 hr, compared with 10^6–10^7 hr for transistors (*6, 7, 8*). The cool operation of transistorized equipment gives an important bonus in the improved reliability of other components.

To realize the advantages of transistor circuits, the designer must deal with problems not encountered in tube circuitry. At present, many of these problems have not been completely solved; hence transistor instruments fail to perform as well as tube instruments in some respects. The user must sometimes accept a performance compromise to obtain the increased reliability, smaller size and cooler operation of transistor units.

The main problems of transistor-circuit design arise from the following factors:

- Semiconductor junctions have appreciable reverse-leakage currents that vary with time and temperature. Silicon transistors are better than germanium units in this regard but inferior in many other respects.
- Different transistors of the same type may have widely different current gains so that circuits must allow for all values of current gain down to a specified minimum (typically ~20 in

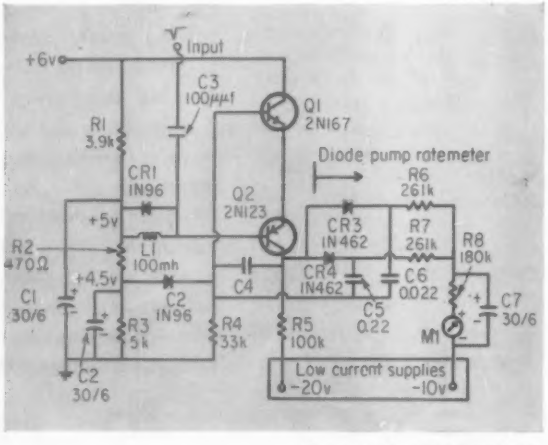


FIG. 2. TRIGGER FOR DIODE-PUMP RATE-METER
Q1 and Q2 are normally nonconducting and the collector of Q2 sits below −10 v so that CR3 and CR4 are nonconducting. Bias across R2 prevents Q1 and Q2 conducting in this condition. A negative input pulse applied via C3 drives Q2 into conduction and its rise in collector potential drives current into the base of Q1 via C4, C5 and C6. Q1's emitter current then drives Q2 still harder and a trigger action results. Conduction continues until C4, C5 and C6 are almost fully discharged; then the circuit triggers back into its nonconducting state. Following this, the charge in C5 and C6 leaks via R6, R7 into the averaging and metering circuit (C7, R8, M1). The meter reading depends upon the input-pulse rate and the circuit constants can be chosen to produce certain desirable types of scale (e.g. logarithmic). The negative-voltage low-current supplies may be obtained from the same generator that furnishes the G-M voltage supply. The circuit is an example of the application of complementary transistor pairs; Q1 is an npn-type junction transistor while Q2 is a pnp type

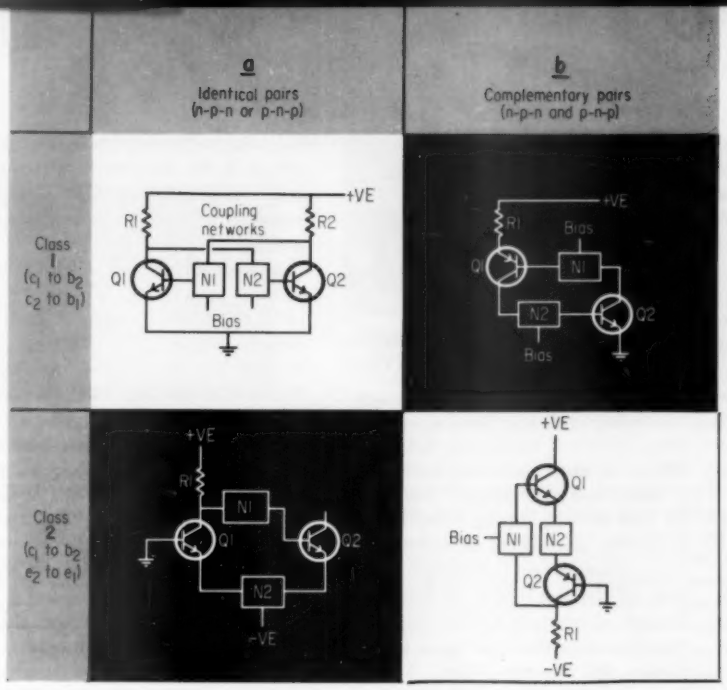


FIG. 1. TRIGGER CIRCUITS use transistor pairs in four basic arrangements. Transistor units (circular symbols marked Q) of npn type are shown with arrow on emitter directed away from base; emitter arrow for pnp is into base. Boxes marked N are coupling networks

the grounded-emitter connection).

• Until very recently the limited bandwidth of transistors has resulted in complex design problems for applications such as wideband amplifiers.

• The input and output circuits of transistors are not as well isolated as they are in vacuum tubes. This makes the design of many transistor circuits, such as feedback amplifiers, quite difficult.

We will now go on to explore in detail some of the circuits that are using transistors with various degrees of success and suggest other circuits in which transistorization may prove beneficial. [For explanations of the basic workings of transistors, we refer the reader to textbooks (*9–21*) already published on the subject.] The circuits given are drawn largely from my own experience and reflect my own personal preferences in circuit design.

Switches and Triggers

Transistors make very good electronic switches. Hence, transistors have had most of their success to date in switching circuits for kicksorters, scalers and ratemeters.

If the emitter of a transistor is grounded and the base-to-emitter junction is reverse biased by the input signal, the impedance between the collector and emitter is very large (~megohms). When the input biases the emitter-base junction in its forward direction, the collector-to-emitter impedance can be very low (~ohms). These are just the characteristics of an ideal switch.

Transistors are much more efficient than tubes for this purpose, because tubes have appreciable voltage drops in conduction.

Like vacuum-tube circuits, transistor circuits with positive feedback will trigger on small signals and produce controlled wave shapes at the output. Transistor trigger circuits equivalent to the vacuum-tube blocking oscillator (*22*), Eccles-Jordan circuits (*23–25*) and cathode-coupled circuits (*26*) all exist and perform at least as well as their predecessors.

The two kinds of transistors (*npn* and *pnp*) available open up possibilities for new circuits. Fig. 1, which shows the four basic trigger circuits, illustrates this point. The two circuits in column *a* use pairs of identical transistors and are copies of tube circuits. Each of the circuits in column *b* uses complemen-

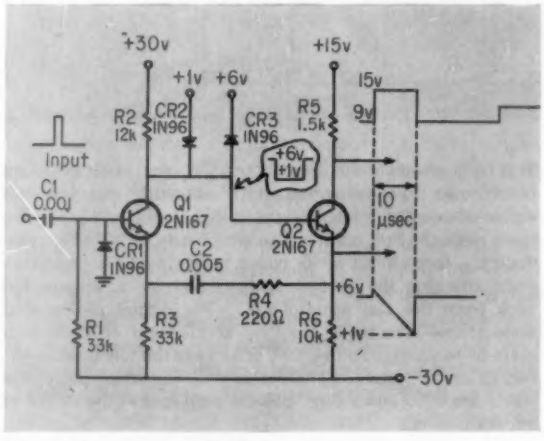


FIG. 3. EMITTER-COUPLED DELAY CIRCUIT

In the rest condition, Q1 passes 1 ma of emitter current determined by R3 and diode CR3 is conducting. CR3 thus clamps the collector of Q1 and base of Q2 to 6 volts. The emitter current of Q2 is therefore 3.6 ma determined by R6 and the collector voltage of Q2 is 9 volts. The drive current to the base of Q2, leakage in CR2 and collector leakage of Q1 rob diode CR3 of current, but the excess of current in R2 over that in Q1 is sufficient to make CR3 conduct. A positive input pulse causes the current in Q1 to increase until diode CR3 becomes nonconducting. The fall in base potential of Q2 cannot be reflected in a sudden fall in potential at the emitter of Q2 due to C2. Thus Q2 becomes nonconducting and the current in R6 flows in the emitter of Q1. This causes the collector potential of Q1 to fall until CR2 conducts. The collector current in Q1 maintains CR2 in conduction despite the current in R1 and leakages in CR3 and the collector-base junction of Q2. When C2 is charged by the current in R6 to the point where Q2 again conducts, the circuit retriggers

tary pairs of transistors (i.e., *pnp* and *npn*) with a coupling system similar to the partner on its left in column *a*. These circuits have no tube-circuit analogs.

In the two states of circuits 1a and 2a, current flows either in one transistor or the other. In the two states of circuits 1b and 2b the transistors are either both "on" or both "off." Moody and Florida (*27*) have described circuits like 1b used in a computer where the low "on" impedance of the circuit is very useful for driving a number of diode gates.

The other circuits also have particular applications. For example, I have used a monostable 2b circuit as a trigger circuit (*28*) to drive a diode-pump ratemeter in a portable G-M counter (Fig. 2). Here the small steady-state current drain of the circuit conserves battery power and the low "on" impedance is ideal for driving the ratemeter circuit. In an alternative described by Franklin and James (*30*), a transistor blocking oscillator performs the same function; the two-transistor circuit of Fig. 2, however, is more sensitive.

The best way to illustrate some of the design problems of transistor triggers is to study a typical circuit. Fig. 3

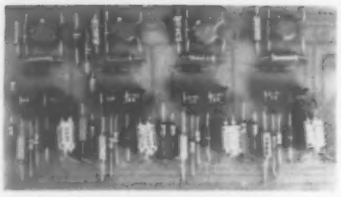


FIG. 4. PRINTED-CIRCUIT decade unit used at Chalk River. See Fig. 5 for circuit diagram

shows a monostable (delay) circuit (class 2a in Fig. 1) used at Chalk River. In this circuit, diodes *CR1*, *2* and *3* overcome the effects of collector and diode leakages and the variable current gain of the transistors. Their second important function is to prevent collector saturation (bottoming) in the transistors and thereby avoid limits on operating time imposed by carrier-storage effects. Diodes used in this way give reproducible circuit performance and also achieve the long life we expect of transistor circuits. Bistable and astable (oscillatory) circuits can also be constructed with the same safeguards against the variations in transistor parameters.

The speed of transistor switching circuits is usually limited by transit-time effects in the transistors (although circuit capacities may also limit speed when very high-frequency transistors are used).

Carrier-storage effects, which can slow down transistor circuits by as much as a factor of 10, are eliminated (as described above) by clamping diodes that prevent collector saturation. When this is done, the transit-time limitation becomes of prime importance. This limit—equivalent to the frequency limit in small-signal amplifiers—is specified by the transistor manufacturer as the alpha cut-off frequency $f_{\alpha o}$.

A scaling circuit, because it requires a short-term memory, usually has a resolving time much longer than the switching time of the transistors. The memory is normally capacitive and time is wasted by the exponential tail; delay-line memories (*29*) allow a closer approach to the ultimate speed. With a capacitive short-term memory, a scaling circuit resolving 1 μsec can use 5-Mc ($f_{\alpha o}$) transistors while 0.1 μsec requires 50-Mc transistors. Recent very-high-frequency transistors give shorter resolving times but little work has been done on them.

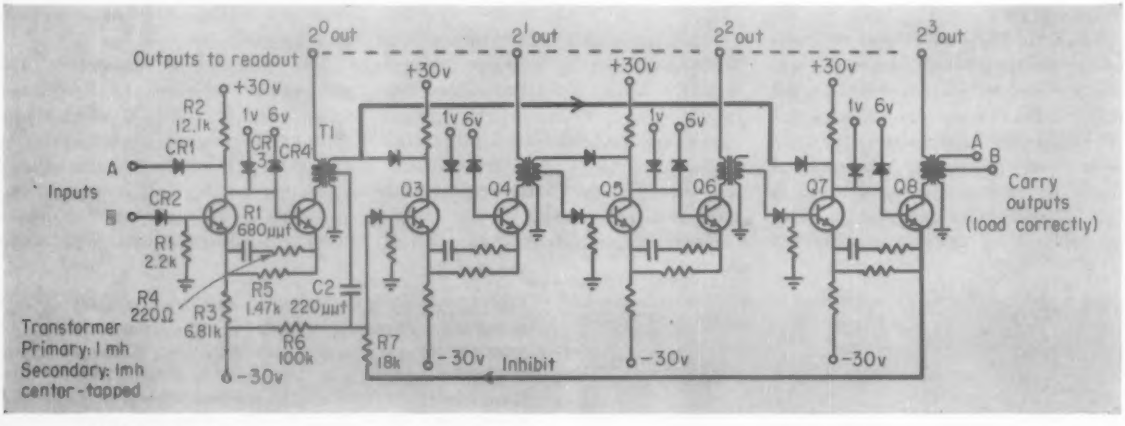
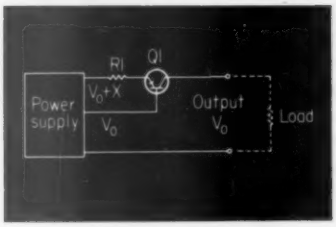


FIG. 5. SCALE-OF-TEN

The unit contains four scale-of-two circuits coupled together to form a scale-of-ten. The operation of the basic scale-of-two has been described (26). If positive pulses are applied to inputs A and B simultaneously (with the pulse amplitude at A half that at B), the circuit built around Q1 and Q2 scales these pulses by two and positive pulses of half the input rate appear at the output of the differentiating transformer T1. Coupling between the first scale-of-two and the second is modified and an extra pulse is fed from the output of the first to the input of the fourth scale-of-two. At the start of counting, all four scales-of-two are reset to zero (Q2 etc. passing about 4 ma) by raising the 1 volt line momentarily to 6 volts.

Scaling proceeds in the normal binary manner until the ninth input pulse. Following the ninth pulse the states of the scales-of-two (from left to right in Fig. 5) are 1001. On the tenth pulse the first scale-of-two switches to its "O" state producing a carry pulse at its ouput. This pulse is prevented from affecting the second scale-of-two by a voltage fed back from the last scale-of-two. The output of the first scale-of-two also feeds the "set zero" input of the fourth scale-of-two and, on pulse #10, this resets the fourth scale-of-two to its "O" state. Therefore, after the tenth pulse, the states are 0000 and a carry pulse is produced at the output of the scale-of-ten

Transistorized Power Supplies for Transistorized Circuits



TRANSISTOR CURRENT LIMITER FOR POWER SUPPLY

The output voltage V_0 from the power supply is fed to the base of Q1, and a voltage somewhat higher ($V_0 + X$), also produced by the power supply, is fed via R1 to the emitter of Q1. The emitter current of Q1 is therefore X/R1 and, if the load current is smaller than $\alpha X/R1$, the collector voltage is almost the same as the base voltage V_0. If the load current exceeds this amount the output impedance of the supply becomes large and the output voltage drops

Transistors are becoming popular not only for nuclear instrumentation circuits (see the accompanying article), but also for the power supplies that power these circuits. Semiconductor rectifiers are already well-established. Series-shunt-type regulators that use transistors are also quite common and have designs similar to their vacuum-tube equivalents. However, two problems come up in transistor power supplies that differ from those of vacuum-tube circuits. The first is the ease with which semiconductor components are ruined. To overcome this, methods of limiting the current available from a power supply have been developed; figure at left shows one such arrangement.

The second problem arises in supplying the convenience of a large number of voltage lines for pulse and switching circuits. Fortunately, these voltages do not usually have to be highly stable or free from ripple. One method of getting multiple voltage lines with about 2% stability is to control the a-c voltage appearing on the primary of the power transformer with a transistor regulator (*60*).

Transistors and other semiconductor components also have advantages for high-voltage power supplies, such as supply radiation detectors (*61*). Several laboratories now use or are developing audio-frequency (~20 kc) transistor oscillators that drive high-voltage transformers with feedback from the high-voltage output to control the oscillation amplitude. Zener-diode reference elements that have stabilities almost comparable with standard cells are now available and provide ideal voltage-reference sources for the supplies. A pair of power transistors can produce up to 40 watts of high-voltage output; the high frequency of oscillation means that transformers and smoothing capacitors are not prohibitively large.

Switching Circuits

One of the important jobs of nuclear instrumentation is that of counting, sorting and recording electrical pulses. Transistors are rapidly replacing vacuum tubes in circuits of this kind; the switching circuits described in the previous section can be used here. Because the reliability, small size and low-power consumption of transistors make possible much more complex counting equipment, the trend is now toward completely automatic data gathering and processing.

Scalers. Although many articles have described basic transistor scaling circuits (*24*, *25*, *29*, *31*), little information has been published on complete scalers. Our effort at Chalk River has been directed towards producing a scaler for automatic readout (*32*); we now have a large number of these units in operation. A photograph of the printed-circuit decade unit is shown in Fig. 4 and a simplified circuit diagram in Fig. 5.

The transistors in this circuit have $f_{\alpha 0} > 5$ Mc. The circuit reliably resolves pulses 2.5 μsec apart. Changes in the values of memory capacitors and differentiating transformers would give improved resolution, but these same changes would reduce operating margins. Higher frequency transistors are required for resolving times less than 1 μsec.

The four outputs from the scale-often unit give a binary code that can be used to punch standard IBM or Datatron codes on paper tape or to operate other output devices. For visual indication, the circuit uses four indicator lamps wired to read the 8, 4, 2, 1 code from a decade unit. Because the circuit is designed for automatic scaling and readout, only one decade unit indicates at a time; the indicator can be switched to any unit in the scaler which contains up to ten such units.

Visual indicators present a difficult problem for transistor circuits. All gas-discharge devices with cold cathodes require signal voltages much higher than those normally produced in transistor circuits. While combinations of high-voltage transistors and neon indicators are sometimes used, the arrangement is not ideal. Electromagnetic movements (e.g. flag indicators) are available but are expensive and wear out under certain scaling conditions. Franklin (*33*) has described a magnetic-compass-type indicator but this is not yet in general use.

One solution is a device that uses small signals for control and higher voltages only for bright illumination. The KIP series* of subminiature thyratron indicators and the Ampex 6977 fluorescent indicator tube are examples. Unfortunately, the presence of filaments detracts from their value. Recently very low-power indicator lamps have become available (GE No. 344), which Graveson has used with transistors. Electroluminescent indicators look promising but no suitable indicators of this type are available at present.

A combination of Dekatrons and transistors offers a possible solution to the indicator problem and also a reduction in the cost and complexity of the complete scaler. In the same way that earlier scalers used Dekatrons with either vacuum or cold-cathode tubes as coupling elements, Chaplin and Williamson (*31*) have described a circuit in which transistors couple the Dekatrons. This circuit is able to operate at the maximum speed of the Dekatrons, ~4 kc.

In many instances two or three fast decades followed by a mechanical register form an ideal scaling system. Chaplin and Williamson (*31*) describe a drive circuit for a register but the drive power produced by this circuit is not adequate to operate many types of registers. Since their report, high-power transis-

* KIP Electronics Corp., Stamford, Connecticut.

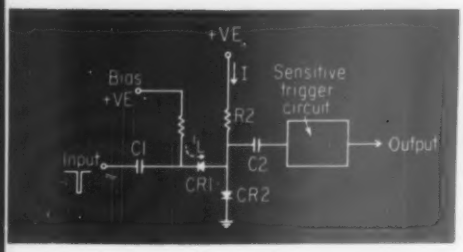


FIG. 6. DIODE DISCRIMINATOR
Diode CR2 is normally conducting with bias current I. CR1 is reverse biased by the positive d-c voltage on R1. A negative input pulse overcomes the reverse bias on CR1 and causes this diode to remove part of the current I from diode CR2. This produces a voltage pulse across CR2 that triggers the trigger circuit

tors have appeared that will supply adequate drive. Transistor-relay drivers have recently seen extensive use by J. Leng (*34*) at Chalk River.

Ratemeters. Many of the techniques developed for vacuum-tube ratemeters (*35*) apply to transistor ratemeters with transistor trigger circuits replacing the vacuum-tube equivalents. The ratemeter in Fig. 2 is an example. However, difficulties arise when an output amplifier has to drive a high current load (e.g. a 1-ma recorder). To reach outputs of this level, one needs a transistorized d-c amplifier that will accept a d-c current of about 50 μa (the level at which satisfactory averaging at low rates can be performed with reasonable-size capacitors). But, as we will see later, such amplifiers have difficulties with leakage and drive currents that change with time and temperature.

Pulse sorters and data handlers. While amplifiers, high-voltage supplies, ratemeters, etc. have changed very little with the years, the sorting equipment following these units has become quite complex. As nearly all this equipment is digital (i.e. no analog circuits) it is an ideal field for transistors. Transistorized multichannel pulse-amplitude analyzers, timesorters and other sorting instruments have been developed by several groups (*36–39*) and exploited commercially. The digital techniques are almost the same as those in computers.

Kicksorters. Nearly all modern multichannel kicksorters have computer-type storage to record input pulses. Each pulse entering the unit is converted into an address code for the storage, the code depending upon pulse amplitude. The first step in producing the code is to charge a capacitor through a diode to the peak pulse amplitude. If the amplitude is to be remembered accurately, leakage in the diode through its back resistance and reverse-transient effects (capacity and carrier storage) must be kept small. These factors are also important for pulse lengtheners. The ideal diodes are fast diffused-silicon types (*40*) but these have only recently come into production; previously, fast alloy-junction silicon diodes (e.g., 1N252) or germanium gold-bonded diodes (e.g., Q5–100) have been used. L. B. Robinson (*44*) has used a series combination of a fast-recovery diode (which has large d-c leakage) and a silicon-junction low-frequency diode (poor recovery but very low d-c leakage); in this way he gets some of the advantages of each type of diode.

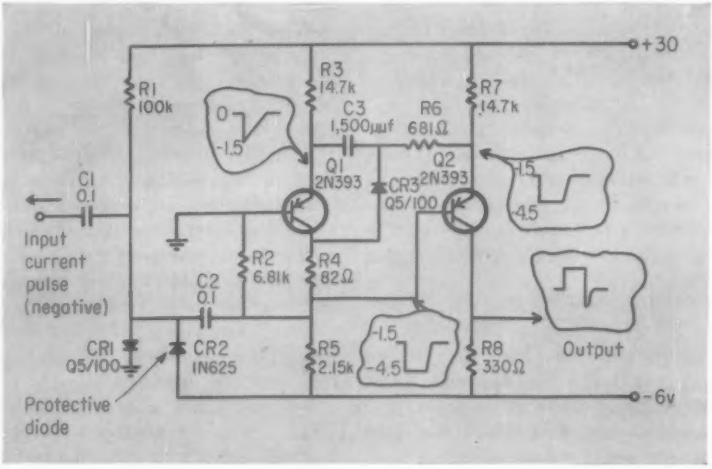
A short period of time after the capacitor has been charged, it is discharged by a constant current or by a diode pump with a staircase waveform. The time required for the charge on the capacitor to be removed is measured. Transistors and semiconductor diodes can perform all of these operations, although one must be careful that the added circuits do not produce variable leakage currents to the storage capacitor. All the digital operations involved can be performed well by transistors at frequencies up to 5 Mc or so.

Discriminators

The nonlinear behavior of semiconductor junctions at low levels becomes important for discriminators. Generally speaking, the voltage drop across a semiconductor diode at constant current is more constant with time than that of a vacuum-tube diode but more dependent on ambient temperature. Fortunately, a large part of the temperature dependence is the same for diodes of a given type, so that there is some hope of compensating for temperature effects.

Figure 6 shows a simple application of this principle to a voltage discriminator. The accuracy in determining the amplitude of the input pulse is limited by the diode leakage i_l in *CR1* (which causes a d-c drop across *R1*), by relative changes with temperature of the voltage drops in *CR1* and *CR2* (which become important when the

FIG. 7. CURRENT OR VOLTAGE TRANSISTOR DISCRIMINATOR
This circuit contains a pair of transistors coupled together in a trigger circuit [Class 2(b) of Fig. 1] with both transistors conducting in the steady state. The circuit is potentially unstable but the forward-biased discriminating diode CR1 shunts the collector load of Q1 at frequencies passed by C3. This reduces the loop gain of the trigger circuit below unity and so stabilizes it. Any disturbing input-pulse signal that reduces the current in diode CR1 below a certain critical level will operate the trigger circuit and cause it to execute a single cycle with the waveforms shown. The circuit has a dead time of about 1 sec with a very fast recovery time



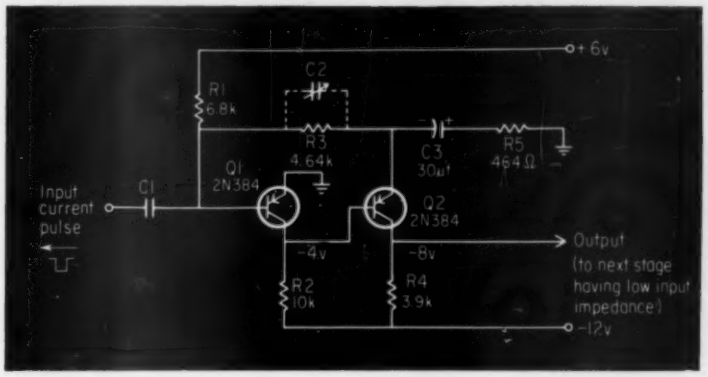
diode currents produce an output signal just adequate to operate the sensitive trigger circuit) and by the capacitive and storage currents in *CR1* and *CR2* respectively. The effect of i_l can be reduced with silicon diodes (in many types the leakage current is less than 0.25 μa at 55° C) and a small value for *R1*. Tests on the balanced arrangement in Fig. 6 show that the cancellation of voltage changes in the diodes is good to about ± 10 mv over a $\pm 10°$ C range of temperatures with no diode selection and that selection of diodes improves this result still further. Fast recovery and low-capacity silicon diodes are necessary to reduce frequency effects (*40*).

Because the drift of semiconductor diodes (± 10 mv) is better than that of vacuum-tube diodes (± 50 mv), the designer can increase the discrimination or window-width accuracy in circuits operating at pulse levels common for existing systems (up to 50 volts) or, alternatively, get existing accuracies at reduced pulse levels. A reduction in signal level by a factor of 5 or so would ease the serious problems now faced in designing the output stage of wideband amplifiers. Moreover, the pulse voltages in the output stage of such amplifiers would then come within the voltage-handling range of transistors.

Another approach to the low-level discriminator problem is the Kandiah arrangement (*41, 42*) of transistors and semiconductor diodes. A circuit of this type (Fig. 7; for corresponding tube circuit see p. 71) was described recently (*43*) that can serve as a current or voltage discriminator. It is particularly convenient as a current discriminator when a transistor amplifier precedes it.

The necessary triggering condition is that the incremental diode impedance (of *CR1*) must exceed (in absolute value) the effective negative impedance produced by the trigger circuit at the collector of *Q1*. The input current signal required to do this is determined partly by the diode characteristics and partly by the bias current (determined by *R1*) in the diode. Triggering accuracies of about ± 1 μa are possible over periods of several days and a temperature range of $\pm 10°$ C. The circuit also works as a voltage discriminator when positive voltage signals are fed into the base of *Q1*. In this mode it has accuracies of about ± 1 mv in triggering and designs are possible that will trigger from signals of 10 mv or less.

FIG. 8. BASIC PULSE-CURRENT-AMPLIFIER STAGE
The feedback via R3 fixes the stage gain and d-c conditions. The medium-frequency gain of the circuit is almost equal to α_2(R3 + R5)/R5 (where α_2 = current gain of Q2). With the values and transistors shown, the current gain is 11 and the bandwidth is about 10 Mc (for zero-impedance load). The 2N384 transistors have α cut-off frequencies of about 100 Mc. Delay-line shaping can be used in the collector circuit of Q2 if desired



The circuit in Fig. 7 has a dead time of about 1 μsec and a very fast recovery because of the fast recharging of *C3* by *CR3; R4* serves to speed up this recovery process slightly. The short recovery time reduces the dependence of the circuit triggering threshold on repetition frequency.

FUTURE USES

So far we have discussed circuits in which transistors are rapidly replacing vacuum tubes (i.e., pulse and switching applications). Now we want to consider areas where transistors have yet to establish their superiority over vacuum tubes.

Pulse Amplifiers

Although transistor amplifiers satisfy many specialized applications (*45–47*), such as health instruments where simple circuits can be used, design of transistor amplifiers with sufficient versatility for nuclear-physics research is another problem. Here very high performance may be demanded, particularly with regard to bandwidth, gain stability and linearity. Also, good overload performance is often required and noise may be a serious problem. With regard to this last factor, A. R. Jones has investigated the noise in transistor amplifiers for ionization chambers and concluded that his best transistors (this was in 1956) were about a factor of ten worse than tubes in signal-to-noise ratio under optimum conditions (*48*). Despite recent improvements in transistors in other respects, little improvement has been realized in this area. We can reasonably conclude that vacuum tubes will continue in use for low-noise ionization-chamber preamplifiers but that transistors will replace tubes in the later stages of amplifiers.

Until recently, it has been difficult to have large negative feedback in transistor amplifiers: the existing transistors did not have adequate gain and small enough phase shifts over the frequency range needed for general-purpose nucleonic amplifiers up to ~10 Mc. Now we have several types of transistors with $f_{\alpha 0}$ ranging from 100 to 750 Mc that should be useful in future pulse amplifiers. Insertion of time constants external to the transistors will simplify the design of the feedback stages. With this improvement and the new transistors, we can expect to achieve gain stability, linearity and frequency response adequate for most purposes.

A slight problem may still exist at the output stage of the amplifier that feeds the kicksorter. The collector-voltage range of high-frequency transistors will probably limit output signals to about ± 10 volts so that kicksorters will have to analyze signals of this level. As seen earlier, drifts in semiconductor diodes used as discriminators are small enough to analyze 10-volt pulses.

In practice, it is considerably more

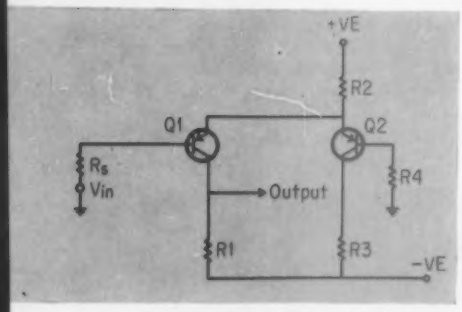


FIG. 9. SIMPLE D-C AMPLIFIER
Input signals (V_{in}) are fed to the base of Q1; the circuitry associated with Q2 is included to partially compensate for temperature effects in Q1. The current in R2 shares between the emitters of Q1 and Q2. The values of R3 and R4 are chosen to minimize temperature effects in the whole circuit. Drifts arise because of changes in the emitter-base voltages of Q1 and Q2 and variations in leakage and drive currents of Q1 and Q2 that flow in R_s and R4, respectively, producing voltage changes across these resistors

difficult to design transistorized voltage amplifiers than current amplifiers (i.e. having low input and high output impedance). Feedback techniques can raise the impedance looking directly into the base of the first stage but the biasing resistor shunting this input cannot have a large value (because of the transistor-leakage and drive currents that flow in the biasing resistor and thereby upset the d-c circuit conditions). On the other hand, the comparative ease with which low-input-impedance current-amplifying stages can be designed is shown by Fig. 8. This basic design has been used extensively at Chalk River and was also described by Baker (*49*).

D-C Amplifiers

D-c amplifiers are often used in nucleonics, particularly in reactor control, data-logging and safety systems. With redundant units, an over-all system can operate very satisfactorily despite the unreliability of the individual units; however, the penalty is in higher maintenance costs. Substituting transistors for vacuum tubes where possible should reduce these costs. At the present, there is a trend towards data-logging systems for monitoring all reactor information, both nuclear and non-nuclear. With the number of variables to be monitored in the range of 100 to 1,000, one can reasonably predict that such systems will operate reliably only if extensively transistorized.

In all d-c circuits the main problems in applying transistors arise in the input stages. Obviously transistors will work in the higher-level stages of d-c amplifiers if the problems due to drift in the early stages can be overcome. A large volume of literature exists on drift in amplifiers that use semiconductor devices (*50–59*). The most we can hope to do here is to indicate the problems and state the limiting performances achieved with the various circuits.

Experimentally one finds that the most important drift in semiconductor devices is due to temperature; the changes with time are usually quite small. The temperature effects consist of leakage and gain variations and changes in junction-voltage drops. These are illustrated in the circuit of Fig. 9.

This circuit, which appears in many different guises throughout the literature, tries to use one transistor to balance the effect of temperature changes in the other. In practice this balance is not good, although carefully selected transistors can give improved results. When the source impedance is very low a drift of the order of $\pm 100\ \mu v/^\circ$ C is possible with this arrangement at room temperature.

The effects of collector leakage and gain variations become more serious as the source impedance increases. Thus, with germanium transistors and source impedances greater than 10^4 ohms, the collector-leakage and gain-variation effects swamp the drift due to variations in emitter-base voltage drop. This method of compensating drifts is sometimes useful, particularly if silicon transistors are employed to reduce collector-leakage effects (*58*).

A chopper-type input stage is another way to improve drift. A transistor or diode stage converts the d-c input

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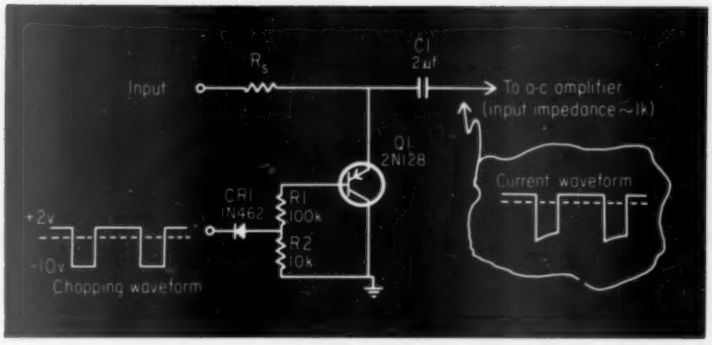

FIG. 10. CHOPPER INPUT STAGE FOR D-C AMPLIFIER
When the cathode of CR1 is positive with respect to ground only a small fraction of the leakage current of CR1 (a silicon junction diode) flows into the base of Q1, so that Q1 is therefore almost nonconducting. When the cathode of CR1 is at −10 volts, 100 μa is drawn from the base through R1 and the emitter-collector impedance of Q1 falls to a low value. Thus the input current through R_s is alternately switched through the emitter of Q1 and through C1 into the input of the a-c amplifier

into an a-c waveform that is amplified by a transistor a-c amplifier and rectified at the output. The zero drift then depends upon the performance of the input "switch." The voltage drop in the switch when "closed" and its leakage current when "open" are the limiting factors; their relative importance depends upon the value of the source impedance.

With low-impedance source the voltage drift in a transistor switch (*49*) exceeds that in a mechanical chopper by one or two orders of magnitude but is much better than that in simple vacuum-tube amplifiers. Hence for low-impedance sources, where the excellent drift of a mechanical chopper is not needed, transistors can replace mechanical choppers.

On the other hand, for high-impedance sources, silicon-diode modulators (*57*) are probably the best semiconductor choppers. But then leakage-current drift—of major importance in these applications—is much inferior to that of electrometer tubes or vibrating-reed electrometers. Thus, although semiconductor choppers have a very useful range of performance, this range does have limits.

A typical chopper circuit for low-impedance sources is shown in Fig. 10. The performance of this type of chopper is described by Chaplin (*51*). The voltage error introduced by a chopper in this circuit in the "on" condition may be less than 100 μv while the current error due to leakage in the "off" condition is less than 10^{-8} amp (each of these figures is for temperatures of 20–50° C).*

For low-current high-impedance sources better results are obtained with a silicon-diode ring modulator described by Moody (*57*). The equivalent input-current drift of a stage of this type may be smaller than 10^{-9} amp at 20–50° C; future improvements in silicon diodes may yield still better results.

* * *

Stimulating discussions with several of my colleagues have resulted in much of the information contained in this article. Information has also been obtained from R. F. Shea and H. D. LeVine who were both kind enough to write giving details of their work and suggesting topics for discussion.

The author also thanks the President of Atomic Energy of Canada Ltd. for permission to publish this article which contains knowledge derived from the program of the Research Division.

* I know of no theoretical treatment that predicts these low drift figures whereas the results presented earlier are reasonably predictable. Further work on transistor choppers therefore seems to be necessary.

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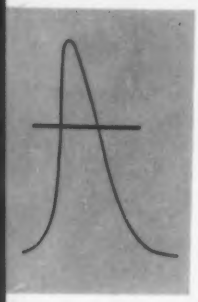

Modern designs are reaching new standards of stability, linearity and resolution. New discriminators that work at millivolt levels may reduce demands now placed on amplifiers

DISCRIMINATORS

By KENNETH A. McCOLLOM, *Phillips Petroleum Co., Idaho Falls, Idaho*

PULSE DISCRIMINATOR design in recent years has tried to get better stability, response to fast pulses, response to very small pulses, and good resolution of close pulses. Low-threshold discriminators have been introduced by Kandiah. However, much needs to be done to satisfy current requirements for detectors.

For the accumulation of good detector data for radiation measurements, one would like to have a discriminator with the following characteristics:

- stability of 1% in the millivolt pulse-amplitude range
- linear response and stability over a range of at least 100 times minimum acceptable pulse amplitude
- resolution for two successive pulses at least as good as 0.5 μsec without change of threshold
- equal response to equal-height pulses varying in width from 10 mμsec to >1 μsec
- no spurious responses from pulses 1,000 times as great as the minimum acceptable amplitude

It should be remembered, however, that the design of a stable amplifier is a problem inseparable from discriminator design for a completely satisfactory instrument. Amplifier stability better than 0.01% is required and also the ability to handle, without spurious effects, pulses 1,000 times the minimum useful threshold.

Design Considerations

A pulse discriminator is a nonlinear circuit element with a discontinuity in its voltage-current characteristic at a threshold of current or voltage. Ideally the output would be zero up to the threshold; beyond the threshold the signal would be reproduced linearly for some applications, nonlinearly for others. The amount of control required in the nonlinearity depends on the application. Pulse-amplitude spectra vary considerably depending on whether the detector is a proportional counter, scintillator, crystal counter or Hornyak button.

Proportional counters and scintillation detectors create demands for both linear pulse amplifiers and pulse-amplitude discriminators with designs that do not limit their capabilities as detectors. Crystal counters and Hornyak buttons produce even greater demands in stability.

A satisfactory pulse-height discriminator must have adequate frequency bandwidth, adequate resolution and satisfactory dynamic overload characteristics.

Bandwidth must be great enough to handle pulses of varying shapes and amplitudes. The threshold device must subtract the threshold voltage and the output must register the remaining amplitude accurately. Narrow pulses come from the quick response of some detectors such as certain organic scintillators and also from sharply peaked pulses that just exceed the threshold (*1*).

Detector pulses as presented to the discriminator may have both varying shapes and varying amplitudes. The threshold device must have a high degree of independence from wave-shape fluctuations in its action of subtracting a predetermined portion from the lower part of the pulse. The output circuit of the threshold device in turn must have sufficient frequency response. It must be able to retain accurately the amplitude of that portion of the pulse above the threshold after the discriminator acts.

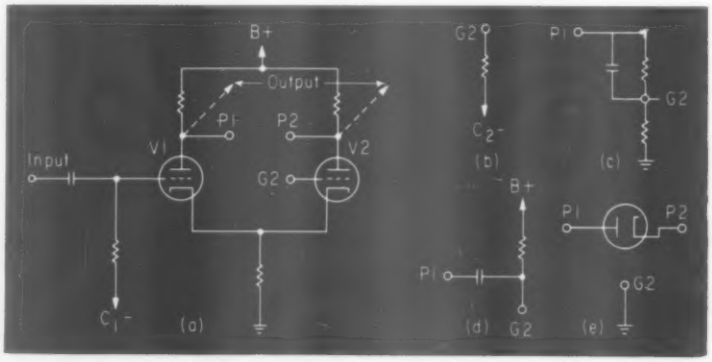

FIG. 1. DIFFERENCE AMPLIFIER can be connected as comparator, trigger circuit or monostable multivibrator to make high-level discriminator

Resolution can be defined as the time interval δ required for the threshold to be re-established within an increment ϵ of the value it had before the circuit was disturbed by a pulse. The length of δ depends on time constants and charges in the disturbed circuit. During the disturbance the threshold may be either greater or smaller than it normally is. Another important consideration during the disturbance is changes in circuit impedances, which may be great in regenerative circuits (*2*).

For accurate pulse-amplitude data the discriminator should generate either an output pulse within the threshold level ϵ or no pulse at all—a circumstance difficult to obtain. A careful study should be made of time-varying relationships as they affect the threshold level. Driving impedances into and out of the pulse-amplitude discriminator should be examined closely to determine their effects on the time constants.

Dynamic overload characteristics are particularly important if one is detecting two kinds of particles at the same time. Both amplifier and discriminator must be able to operate in the presence of large overload pulses if much smaller pulses are to be recognized accurately. The amplifier must overload gracefully and avoid double pulsing; the discriminator must not experience altered voltages that will cause spurious pulses.

Discriminating Elements

The commonest discriminating elements are the back-baised diode and the biased-off amplifier. The first is a diode so connected that it is normally subjected to a voltage tending to make current flow in the reverse direction. The diode will pass current in the forward direction only when a voltage pulse overrides the bias. Similarly a biased-off amplifier has a steady-state bias at its signal input of such sign and magnitude that the amplifier passes no current. An input pulse that overrides the bias causes the amplifier to pass current. Either thermionic or semiconductor elements can be used to make either type of discriminator.

Thermionic diodes fall short of ideal linearity mainly because of the finite velocity of electrons emitted from the cathode. Zero current and zero voltage do not occur simultaneously. The position of the discontinuity in the voltage-current characteristic depends on cathode temperature and work function of the cathode surface.

Crystal diodes do not have this difficulty, but their characteristics change with temperature. Since dynamic resistance of the diode is one of the circuit parameters establishing the threshold, most circuits have an uncertainty in the threshold of ~0.1 volt.

Considering both sharpness of nonlinearity and interelectrode capacitance one concludes that crystal diodes are probably better threshold-establishing elements than thermionic ones. Interelectrode capacitance is always a problem because it passes a portion of the signal even when the signal is below the threshold. In thermionic diodes this capacitance is ~2 $\mu\mu$f and essentially constant. Signals of the proper phase and polarity to counteract that passed by the interelectrode capacitance—called "paraphase" signals—can be introduced at various points of the circuit (*3*). In crystal diodes the interelectrode capacitance ranges from 0.2 to 500 $\mu\mu$f depending on type. Compensation is difficult because capacitance varies with reverse voltage. For a given forward resistance, silicon diodes have greater capacitance than germanium ones. However, small capacitances are available, and sharp nonlinearity gives the crystal diodes significant advantages.

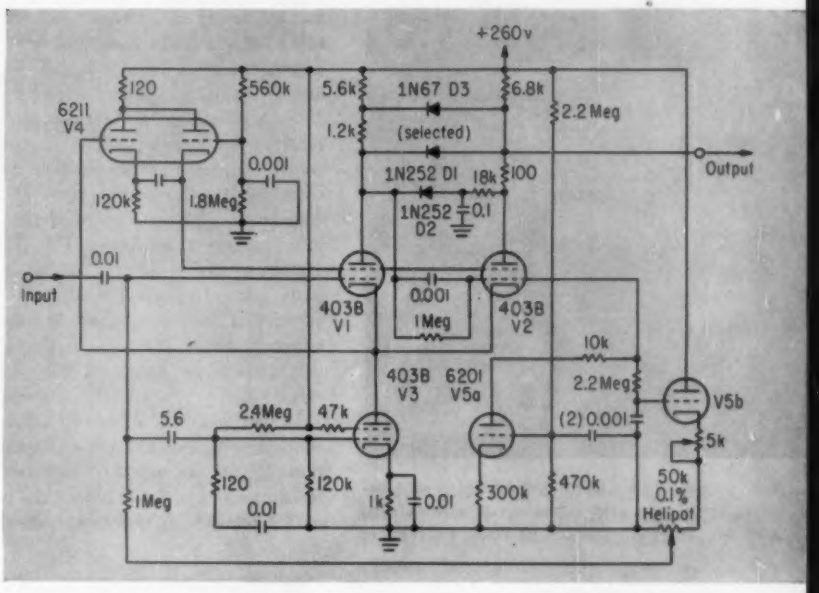

FIG. 2. HIGH-LEVEL DISCRIMINATOR uses several features of Fig. 1 simultaneously. Breakaway diode D1 sharpens response

Biased-off thermionic amplifiers have the same threshold drifts as thermionic diodes. Moreover shifting of additional electrode potentials may change the cut off. Transistors stand in the same relationship to thermionic amplifiers as crystal diodes to thermionic diodes. Temperature variation in I_{co}, bias current for zero emitter current, also causes trouble. Introduction of control elements in the circuit causes additional fluctuations.

High-Level Discriminators

A high-level discriminator can be defined as one with a threshold between 1 and 120 volts. Amplifying the input pulse to this range of amplitudes reduces the importance of the basic uncertainty in the threshold of back-biased diodes and biased-off amplifiers.

A commonly used high-level discriminator is the difference amplifier of Fig. 1. Connected as shown in Fig. 1b and properly adjusted, the circuit gives a voltage difference at the plates proportional to the voltage difference at the grids. To make a discriminator one adjusts C_2^- so that *V2* is conducting and C_1^- so that *V1*

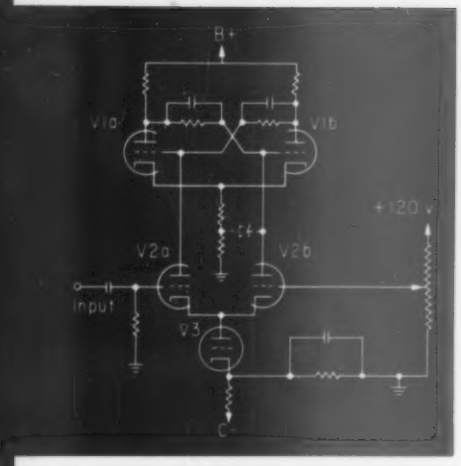

FIG. 3. COMPARATOR circuit replaces grid resistors of symmetrical multivibrator for 10–100 mv threshold

is cut off by the amount of the threshold.

Connecting the circuit as shown in Fig. 1c makes a Schmitt trigger circuit, and the arrangement of Fig. 1d makes a cathode-coupled monostable multivibrator. Both add regeneration above the threshold to the basic difference circuit.

The breakaway-diode circuit of Fig. 1e is nonlinear when the diode stops conducting rather than when *V1* starts. In the equilibrium condition the diode conducts; so the plate current of *V2* is divided between the two plate resistors. When a positive pulse causes *V1* to conduct more current, the two plate potentials remain equal unless the increase through *V1* is great enough to cause the diode to cease conducting. At this point the two tubes are operating at maximum gain, and the result is a sharp break in the characteristic.

These balanced circuits reduce the effect of heater-voltage fluctuations by a factor of ~10 (*4*) and the effect of variations in plate-supply and bias voltages by a factor of $\sim\mu + 1$ as seen at the cathodes.

Contact (electron-affinity) potential differences between grid and cathode can cause threshold uncertainties of ~0.1 volt. The problem is further complicated by the fact that these potentials change with aging of the tubes.

An example of careful use of some of these techniques is shown in Fig. 2 (*5*). The difference amplifier, *V1* and *V2*, has two high-transconductance tubes for a large frequency bandwidth. There is also a breakaway diode *D1* and a Schmitt trigger arrangement. *V3* holds constant the total plate current for *V1* and *V2*. The paraphase signal, injected through the 5.6-μf capacitor to the control grid of *V3*, counteracts the pulse coupled through grid-cathode capacitance in *V1*. When *V1* draws 3 ma of the 7.5-ma total plate current, diode *D1* cuts off, and the circuit becomes a modified Schmitt trigger circuit. *D2* limits the grid-voltage change available for *V2* to ~0.9 volts.

It also slows the return to quiescent condition in that the 0.1-μf capacitor must charge through the small forward resistance of the diode before the plate of *V1* reaches its quiescent potential.

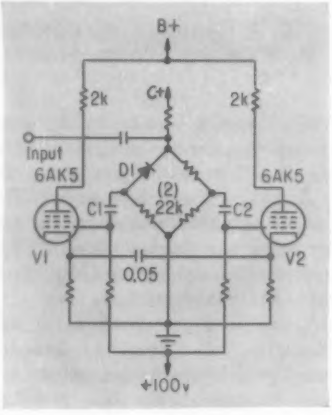

FIG. 4. FAST BRIDGE circuit responds to very short pulses

Threshold hysteresis with these parameters is ~0.3 volts and is determined by the current reduction in *V1* necessary to bring the current in *D2* to zero. Hysteresis is defined as the difference between the voltage on the rising pulse that triggers the circuit from its quiescent condition and the voltage on the falling pulse at which the circuit can return to quiescent from its nonquiescent state.

V4 speeds the return to quiescent conditions. One section is a bootstrap cathode follower and the other recharges the screens of *V1* and *V2* to keep their potentials at a desired value. Zero reference for the grid of *V1* is set by *V5b* from the average potential on the grid of *V2*. The A-8 amplifier that drives this discriminator has outputs to 120 volts with a rise time of 0.18 μsec.

A General Radio Co. circuit has specifications indicating that a good pulse-amplitude discriminator could be based on it (*6*). The circuit compares a linearly increasing potential with a fixed one to produce time delays as small as 1 μsec with 1% accuracy.

Figure 3 shows a symmetrical multivibrator with grid resistors replaced by *V2a* and *V2b*. Because of the grid biases, *V1a* is normally conducting and *V1b* is normally off. A positive pulse at the grid of *V2a* will trigger the circuit if it is greater than a threshold that depends on the potential at the grid of *V2b*. Hysteresis as measured at the input grid depends on the amount by which *V1b* is cut off. Typical thresholds are 10–100 mv.

A modification of this circuit with refinements common to multivibrator circuits functions as a discriminator at up to 300 kcps and over a range of 0–120 volts. Attractive features are high input impedance and fast response.

Fast Discriminators

Fast organic scintillators with pulse rise times and durations in the millimicrosecond range have pushed the development of fast circuitry. Of prime importance for quantitative data from such phosphors is a pulse-amplitude discriminator with sufficiently fast response. Two specifications are important: adequate discrimination for a given short rise time and return to quiescent conditions within a specified time. The first of these specifications is not too hard to get. The second requires considerable ingenuity. Invariably one must use tubes with a high gain-bandwidth product.

One of the best discriminators of this type is a simple biased germanium diode. The combination of low effective capacitance, good sensitivity, fast response and simplicity are hard to beat. Temperature control is usually required. There are several ways of improving the diode response in bridge circuits.

Figure 4 shows a simple bridge-circuit discriminator. Its 6AK5's operate with pulses as short as 6 mμsec and almost equally well with pulse durations in the range of 6 mμsec to 1 μsec or more (*7*). Output pulse duration is 3 μsec.

Another fast discriminator is shown in Fig. 5 (*8*). The threshold amplifier

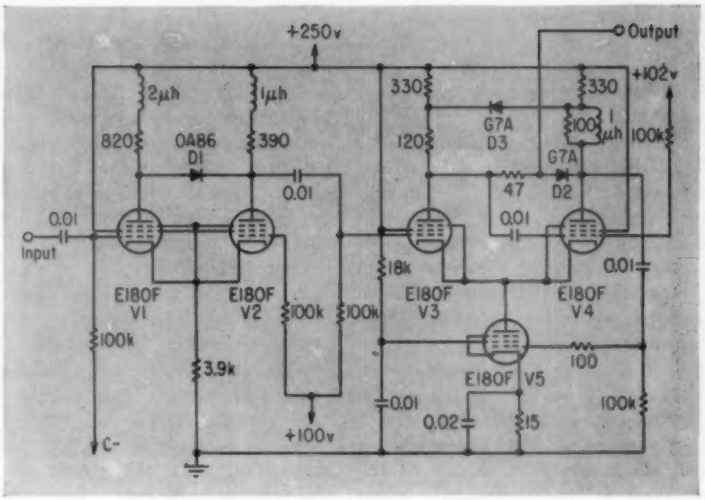

FIG. 5. FAST DISCRIMINATOR has threshold amplifier with breakaway diode and resolves 20 μsec pulses only 20 μsec apart

—*V1*, *V2* and the breakaway diode—provides enough gain for input amplitudes of 1–21 volts. Next is a modified cathode-coupled Schmitt trigger circuit. *V4* is normally conducting. Following trigger action a positive pulse is coupled from the plate of *V4* to the grid of *V5* to accelerate the fall of the common cathode potential. *D2* and *D3* limit the negative pulse on the plate of *V3* to 3.5 volts and the positive pulse on the plate of *V4* to only a few tenths of a volt. Threshold depends somewhat on pulse width, but there is excellent fast response. Two 20-mμsec pulses separated by 20 mμsec can just be resolved.

Secondary-emission tubes are desirable for fast circuits. They are superior to pentodes in gain-bandwidth product. A circuit using these tubes is shown in Fig. 6 (*9*). *V1* amplifies the negative input pulse and provides both current and voltage pulses to *V2*. *V2* has regeneration because of the variable capacitor between dynode and grid. It can have either an astable or monostable operation. Proper grid bias puts it in a monostable condition. From this state a great enough trigger pulse can lift it into a regenerative state in which the loop gain is greater than unity.

Both the variable capacitor and the grid-bias potentiometer of *V1* can change the threshold. The circuit triggers easily with 5-mμsec, 2.0-volt input pulses. An attractive feature is that the 50-mμsec output pulse is almost independent of threshold setting.

Low-Level Discrimination

A new line of low-level discriminators has grown out of the technique of using a negative resistance in parallel with a diode. These are sensitive for pulses of 1–500 mv. The original circuit introduced by Kandiah is shown in Fig. 7 (*10*). A cathode-coupled multivibrator produces the negative resistance, and this is in parallel with a positive resistance offered by the diode.

Operating the diode in the retarding-field region up to ~500 μamp gives a nearly constant dynamic resistance for different tubes of the same type. For higher currents, differences in total emission and changes with time in resistances between cathode sleeves and coatings give inconsistencies between diodes. For lower currents the second effect is negligible because the total resistance is large.

In the circuit of Fig. 7, *V2* is normally conducting and *V1* is biased off. *V3* is adjusted to pass enough current that pulses below the threshold will be clipped by the diode and not trigger the multivibrator. Adjusting the current through *V3* adjusts the threshold. The divider *R1* and *R2* supplies a negative feedback so that changes in the multivibrator circuit do not change the threshold. Contact

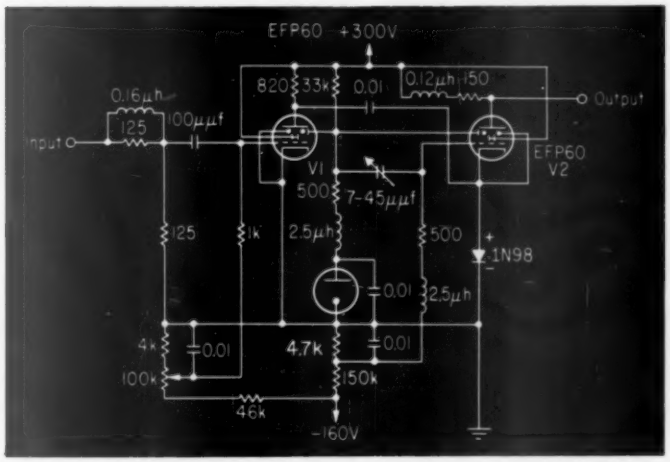

FIG. 6. SECONDARY-EMISSION-TUBE CIRCUIT responds easily to 5-mμsec, 2.0-volt pulses

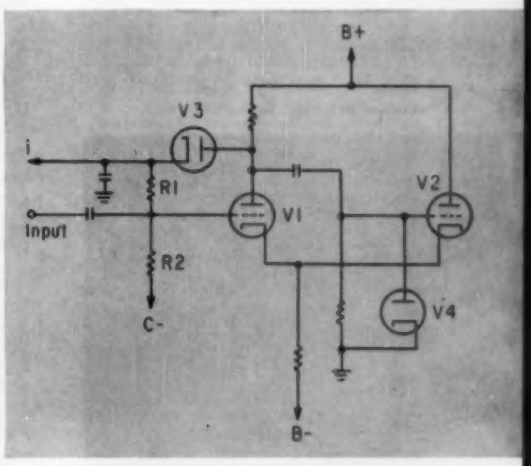

FIG. 7. LOW-LEVEL DISCRIMINATOR uses diode in parallel with negative resistance

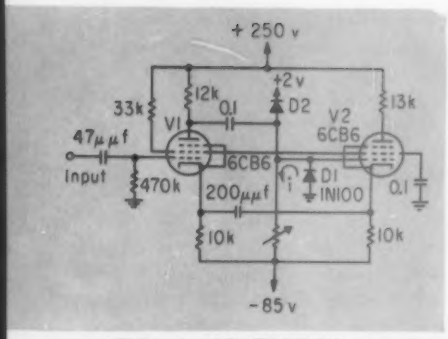

FIG. 8. ADAPTATION improves resolution available with circuit of Fig. 7

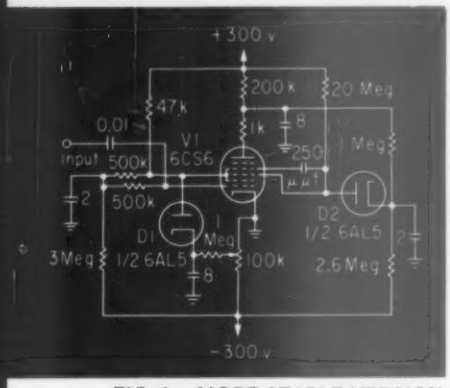

FIG. 9. MORE STABLE VERSION uses negative resistance from cathode to grid

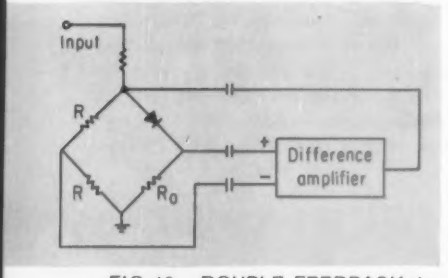

FIG. 10. DOUBLE-FEEDBACK circuit offers high sensitivity

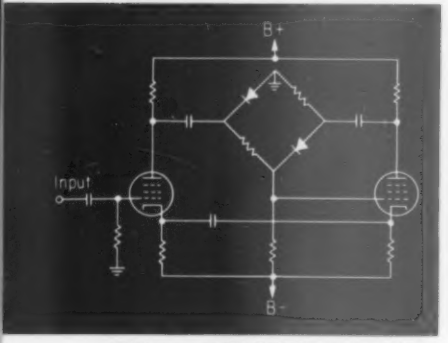

FIG. 11. MODIFICATION of circuit of Fig. 10 has isolated input

potentials of *V1* or *V2* can change by 100 mv, and the diode current will change by less than 1%. Without the divider the resulting change would be 100 ma.

Threshold stability in this circuit allows discrimination at the 100-mv level with 2% accuracy. The threshold is stable to at least 10% down to 20 mv, and the circuit will trigger down to 2 mv. Resolution is ~70 μsec.

Such stabilities at such low levels call for an evaluation of the amplifier-discriminator relationship. Before design of this low-level discriminator, pulses had to be amplified to 5–100 volts to discriminate with 1% accuracy. Discrimination at 1% at the millivolt level eliminates much or all of the amplification formerly required. Some discriminators can follow elements like photomultipliers directly with a corresponding reduction in the amount of equipment required and the inherent sources of trouble.

One disadvantage of the original Kandiah discriminator is poor resolution. The circuit of Fig. 8 is an attempt to adapt the basic circuit to rapid response (*11*). Separate cathode resistors to stabilize each tube replace the common cathode resistor and negative plate-to-grid feedback of the original circuit. The thermionic diode is replaced by crystal diode *D1*. A negative input pulse reduces the current in *V1* and also the clamping current in *D1*. At the threshold the impedance of *D1* becomes great enough for a loop gain of unity. *D2* limits the rise allowed to the control grid of *V2*. The feedback loop is completed by the 200-μμf capacitor that couples the rise of the cathode of *V2* to the cathode of *V1*. Using a 1N100 as *D1* results in ~1-μsec resolution and a threshold of 7–400 mv. Threshold is adjusted by the potentiometer which adjusts the current through *D1* between 150 and 500 μamp. Stability has not been measured yet, but qualitatively it looks good.

A further development to increase resolution has d-c coupling from the plate of *V1* to the grid of *V2* (*12*). It has a threshold range of 20–130 mv and resolution of 1 μsec.

The extension of the Kandiah circuit shown in Fig. 9 uses the negative resistance between screen and cathode (*13*). Negative resistance results from division of current between screen and plate. This system was selected after an investigation to determine the most stable negative resistance available. Voltage sources, screen, plate and cathode currents, and screen and plate potentials are stabilized. As a result the tube has a virtual cathode fed by a constant current and a control-grid potential such as to maintain a fixed ratio between screen and anode currents. Discrimination level is 1–30 mv with 1% stability.

With respect to pulses, *D1* and *D2* are in parallel; their dynamic conductances add. The time interval between initial pulse and return to equilibrium depends only on the current through *D2*; it is independent of threshold, which is set by the current through *D1*. In the circuit shown this interval is 30 μsec. With proper manipulation of time constants and diode currents resolution can be reduced to 4 μsec.

Figure 10 shows a balanced d-c discriminator with high sensitivity (*14*). The significant difference between this and previous circuits is the use of two feedback paths. A positive feedback includes the diode and resistor R_0; negative feedback includes the two resistors R. Net feedback polarity depends on the diode resistance. Loop gain becomes greater than one when a negative input pulse exceeds the threshold and makes the diode resistance greater than R_0. Increasing the gain of the amplifier reduces the threshold.

In Fig. 11 is a sensitive discriminator that resembles the one of Fig. 10 (*11*). The trigger is a negative pulse at the input. Theoretically an unlimited amount of gain can be used to increase speed and sensitivity. Dependence of sensitivity on transconductance can be made negligible. Thus sensitivity can be much greater than diode stability. With temperature control the threshold varies less than 1 mv after temperature equilibrium is reached. Perhaps other nonlinear devices of greater stability can even improve this.

Transistor Discriminators

Replacing vacuum tubes with transistors offers the benefits of greater reliability and smaller power consumption. Another benefit for pulse equipment is inherent low impedance. This reduces the effects of pickup from impulsive control equipment, arc welders, etc.

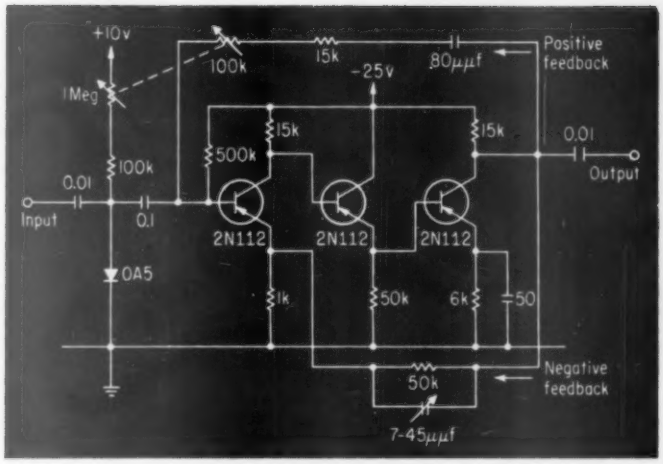

FIG. 12. TRANSISTOR DISCRIMINATOR is based on Kandiah principle of circuit shown in Fig. 7. Negative feedback increases stability; positive feedback creates negative resistance

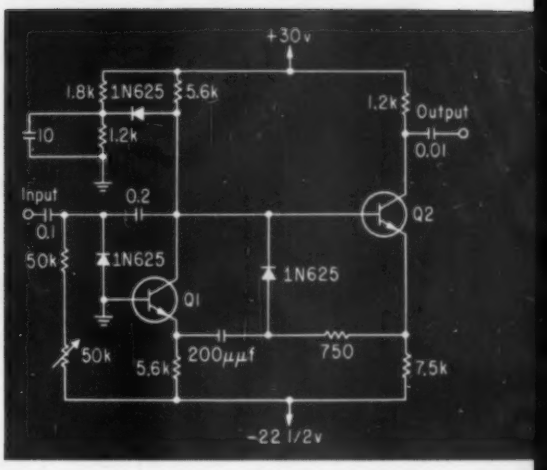

FIG. 13. ANOTHER TRANSISTOR CIRCUIT has smaller gain, less stability but better resolution

A low-level transistor discriminator based on the Kandiah principle is shown in Fig. 12 (*15*). For stability, negative feedback is introduced between the output and the first emitter of a three-stage amplifier. Amplifier gain is 50. Negative resistance between the input terminals is achieved by positive feedback from the output to the first base. The negative resistance is given by $R_{neg} = R/(A - 1)$ where R is positive-feedback resistance and A is amplifier gain.

The diode is the positive resistance in parallel. The result is a current threshold established by the diode current. It is adjustable between 5 and 50 μamp with a stability of 1%.

Another transistor circuit uses the same principle but with smaller loop gain (*16, 17*). It is shown in Fig. 13. Reduced gain leads to a corresponding reduction in threshold stability. On the other hand this circuit has a resolution of 2 μsec, which is better than that of the circuit shown in Fig. 12. Thus this circuit is best used to reject pulses below its threshold when pulse-height distribution is not sensitive to changes of ~10% in threshold.

This circuit is for *current* pulses. However, if a resistor is inserted between the base of *Q1* and ground, the circuit becomes a voltage-pulse discriminator for pulses inserted at the base.

A high-level discriminator is shown in Fig. 14 (*18*). It uses some of the basic techniques described for vacuum tubes. *Q1* and the Zener diode *D1* provide a constant current to the common emitter connection between *Q2* and *Q3*. *Q2* and *Q3* form a comparator. *Q2* conducts all of the current from *Q1* until a positive input pulse exceeds the positive reference. Thereafter *Q3* conducts all the current from *Q1*; collector current from *Q3* becomes large enough to cut *Q4* off; the regenerative pair *Q4, Q5* switches to its second stable state. The transition band in which current is divided between *Q2* and *Q3* can be made as small as 20 mv. The regenerative pair can be thought of as a transistor version of the Schmitt trigger circuit that is described in connection with Fig. 1.

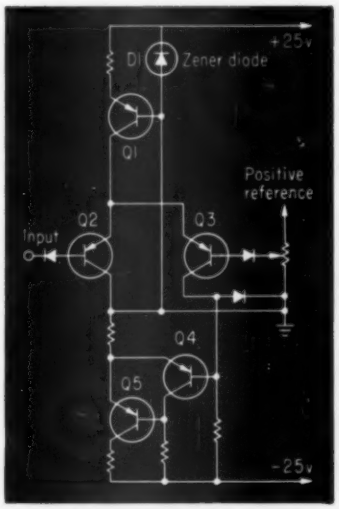

FIG. 14. HIGH-LEVEL CIRCUIT uses vacuum-tube techniques with transistors

* * *

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Scalers have evolved from tube circuits counting by twos to transistorized versions counting by tens. Now the trend is toward increased use of special decade counting tubes

SCALERS

By HUGH F. STODDART, *Baird-Atomic, Inc., Cambridge, Massachusetts*

COUNTING PULSES from a radiation detector is an important part of most nuclear measurements. In early work mechanical registers were used for pulse counting, but even the fastest were slow compared with the rates from detectors. To overcome this problem, it was necessary to divide or "scale" down the counting rate electronically to a level at which it could be measured. These electronic devices are known as binary scalers, having several stages of binary flip-flop circuits, each of which provides an output pulse for every other input pulse.

The Flip-Flop

A flip-flop (FF) is a symmetrical circuit with two stable states, usually distinguished by the binary numbers "*0*" and "*1*." A typical FF is shown in Fig. 1a. Because of the d-c connection, only one section of the double triode can be conducting at any one time. For the purpose of explanation let us designate the state in which the right section of the tube is "on" by the binary *0* and the state in which the left section of the tube is "on" by the binary *1*. If the FF is in state *0* and we force the grid of the right tube momentarily negative, the circuit will "flip" to state *1*. This is termed "setting *1*." If the circuit is already in the *1* state, the act of setting *1* will clearly not "flop" the circuit back to *0*. Likewise, we refer to forcing the grid of the left tube momentarily negative as "setting *0*."

By "steering" an input pulse with diodes biased in an appropriate manner by the FF itself, it is possible to select the act of setting in such a way that the FF always reverses its state. This is called "complementing" and is illustrated in Fig. 1, right. A train of rectangular pulses at the input is differentiated by the *RC* network, producing the indicated waveform. The positive transitions can be ignored since they are blocked by both steering diodes. In the *0* state the negative transition is blocked by the left steering diode but not by the right one. This results in a negative pulse at the right tube grid, causing the FF to be set to *1*. The same reasoning applies in case the FF is in the *1* state originally except that it is the left steering diode that is conducting, causing the FF to be set back to *0*.

The capacitors that have been added across the two grid-plate resistors speed up the regenerative action but are sometimes referred to as "memory" capacitors since they also provide a memory of the previous state throughout a transition. This is because there is a greater charge on the capacitor connected to the grid of the conducting tube than on the other capacitor. Thus, this grid is momentarily swung further off than would otherwise be the case due to the d-c connection alone. This prevents the circuit from "forgetting," half-way through the transition, which way it is going.

An output can be taken from either

FLIP-FLOPS BY EASY STAGES

FIG. 1. D-c connected symmetrical circuit has two stable states; here right-hand tube is conducting. If grid of that tube is carried negative momentarily, circuit will "flip" to state in which left-hand tube conducts. Steering diodes, shown in heavy lines, direct input pulses so as to always reverse state.

FIG. 2. Transistorized version of flip-flop shown in Fig. 1

FIG. 3. More sophisticated transistorization is reflected in transformer-coupled stage shown here

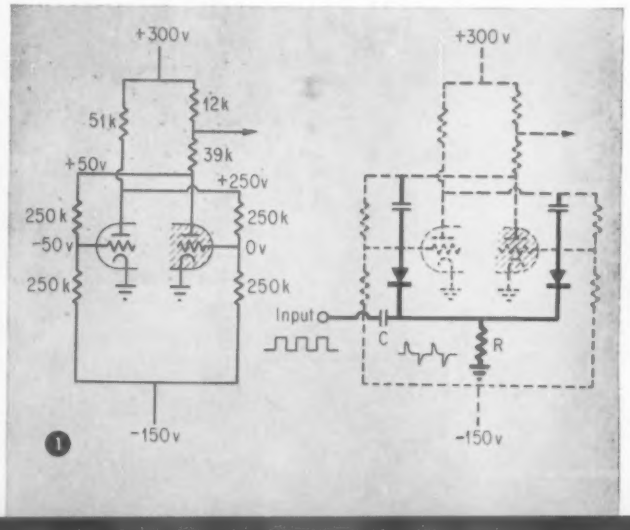


plate-load resistor of the FF. The load resistor is sometimes split as indicated in the figure to avoid placing too much stray capacity directly on the plate For the FF illustrated in Fig. 1 a *1* to *0* transition produces a negative voltage step suitable for complementing another FF. A scale-of-four can be obtained by cascading two FF's.

Figure 2 shows a circuit for a transistor FF that is very similar to the one illustrated in Fig. 1b for a vacuum tube. A more elegant transistor FF, taking better advantage of the characteristics of transistors (*1*), is given in Fig. 3.

Statistics of Counting

In virtually all nuclear uses of pulse counters, the input pulses are distributed randomly in time. If the scaler cannot distinguish pulses close together, it will falsely count two pulses as only one, indicating fewer counts per minute than actually occurred.

The probability of exactly k counts occurring in a time interval t following a previous count is given by the Poisson distribution

$$P_k = \frac{(Rt)^k}{k!} \cdot e^{-Rt} \qquad (1)$$

where R is the average counting rate.

Usually the scaler resolving time is short compared with the average spacing T between pulses. Since $T = 1/R$ we can simplify Eq. 1

$$P_k = \left(\frac{t}{T}\right)^k \cdot \frac{1}{k!} \cdot e^{-\frac{t}{T}}$$
$$= \left(\frac{t}{T}\right)^k \cdot \frac{1}{k!}\left(1 - \frac{t}{T}\right)$$

For $\frac{t}{T} = 0.01$ (i.e. 5-μsec resolving time and average count rate of 2,000 cps) we have:

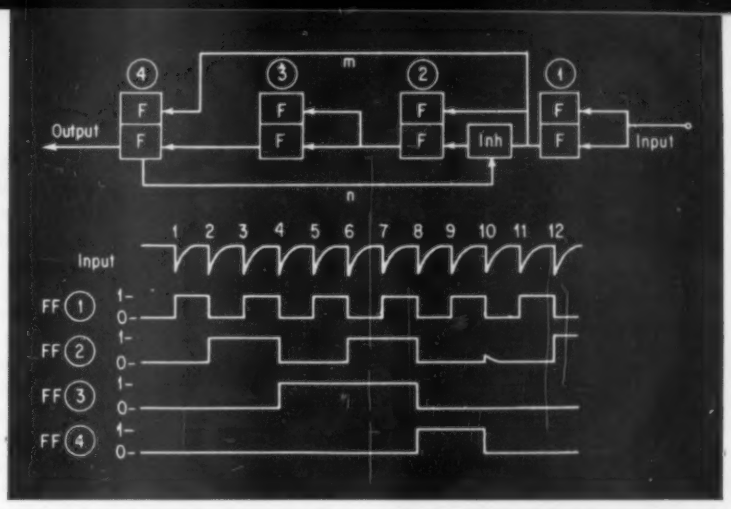


FIG. 4. SCALE-OF-TEN can be built out of four flip-flops by providing an inhibit gate ("Inh" in figure) that keeps FF2 from responding to the ninth pulse in a train of ten. Connection "m" from first to fourth stage resets it on the tenth pulse

$$P_0 \approx \left(1 - \frac{t}{T}\right) \approx 0.99$$

$$P_1 \approx \frac{t}{T} \approx 0.01$$

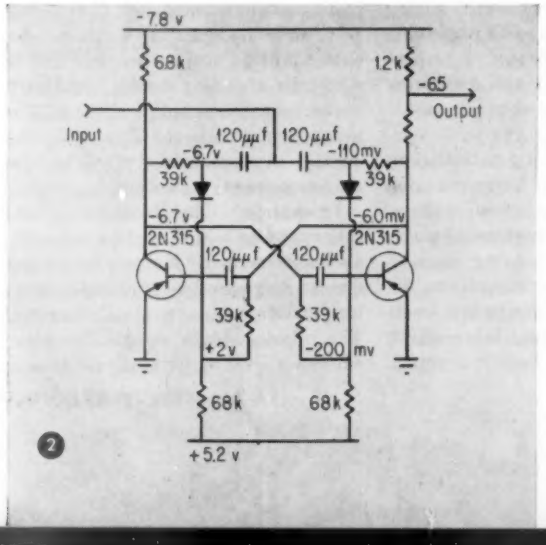
$$P_2 \approx \frac{1}{2}\left(\frac{t}{T}\right)^2 \approx 0.00005$$

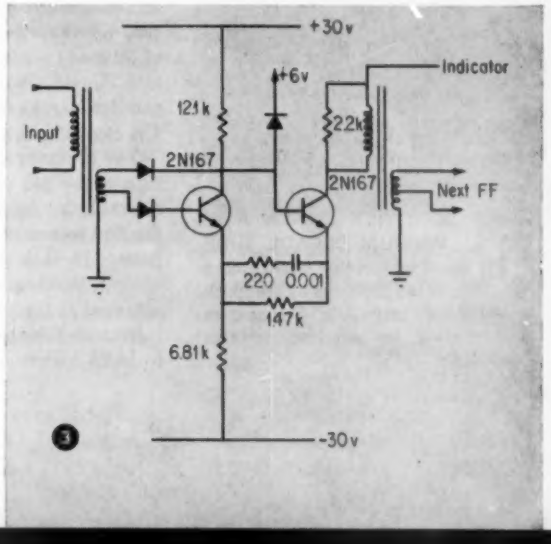
from which we conclude that the greatest loss arising from resolving time errors in the scaler derives from pulse pairs rather than pulse triplets or quadruplets. Thus a rather slow scaler can be made a great deal faster by interposing a single fast flip-flop at its input.

This brings us to the concept of regularization of random pulses by scaler action (*2*). The pulses out of a single binary flip-flop which is being driven by a random source are not only half as frequent but they have also been partly "derandomized" or made more regular in their spacing, and Eq. 1 no longer applies. In fact the output of a scale of 1,000 that is being fed by a random source is so regular that the spacing between pulses varies by only a few per cent from pulse to pulse. For this reason the mechanical register that follows three electronic decades in a typical scaler can be made to run at virtually its maximum continuous rate without any losses, while the first decade, operating at an average counting rate of only one-twentieth of the frequency at which it can count evenly-spaced pulses, is losing 5% of its pulses.

Binary vs. Decade

As long as counting rates were low, the simplest scaler consisted of a few binary flip-flops that slowed and regularized the counting so that a simple mechanical register could be easily driven. The total count accumulated was determined by multiplying the register indication by the electronic scale factor and interpolating the number of counts caught in the flip-flops by reading their states from neon lights. This latter task could be avoided by





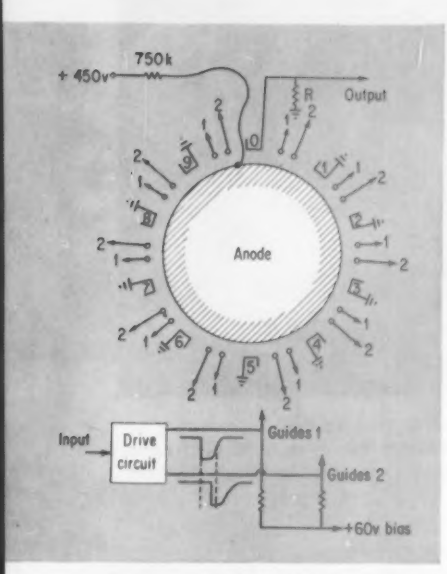


FIG. 5. DEKATRON TUBE has built-in scale-of-ten. Clockwise transfer of glow discharge from stage to stage is accomplished by pulsing first guides 1 then guides 2 negative

making the scale factors small enough so that the few counts stored could be neglected. The desire for equipment to handle faster counting rates as a result of better detectors pushed the required scale factor higher and higher. Opposition to binaries increased with the inconvenience of interpolating progressively longer binary numbers. Although there are a few pockets of resistance still holding out for binaries, most scalers are now decade types.

Decade Scalers

One of the first methods used to obtain an electronic decade consisted of modifying the four cascaded FF scale-of-sixteen. A recent example (*1*) of this technique combines four of the transistor FF circuits of Fig. 3 as shown in Fig. 4.

The relative complexity of the modified binary circuit induced people to think about devices which would be basically decade in nature. Such a component should have ten consecutive stable "states" or configurations and a means of shifting from one state to the next on receipt of an input pulse. One such example is the Dekatron, a ten-cathode gas-discharge tube (*3*). The discharge from the common disk-shaped anode can take place to only one cathode at a time since the current drawn by the "on" gap is sufficient to drop the potential of the anode below the firing points of the other anode-cathode gaps. Transfer of the glow from cathode to cathode is accomplished by pulsing the two guide electrodes, interposed between the cathodes, sequentially negative as illustrated in Fig. 5. This provides an electric field that guides the discharge clockwise around the anode. Pulsing the guides in reverse order forces the discharge to move around the anode in the opposite direction. Each time the discharge passes over the "*0*" cathode, a positive output pulse is produced across the cathode resistor. Transistor (*4*) as well as vacuum-tube (*3*) and gas-tube drive circuits have been used.

Although the leading edge of the glow can be made to move quite fast, the heavy gas ions in its tail are swept out very slowly. Furthermore, the current available to drive the anode capacity is rather small. This limits the maximum speed for counting uniformly spaced pulses to about 50 kc. Although this rate is quite respectable, we recall that it does not apply to the random counts from radioactive material. Assuming a pulse-pair resolution of 20 μsec ($\frac{1}{50}$ kc) and applying equation 1, we find that the maximum random count rate for no greater than 1% counting loss is 500 cps.

The performance of a practical glow tube scaler (*5*) can be improved considerably by preceding it with a single flip-flop to remove closely-spaced pulse pairs. In this way counting rates of several thousand per second can be achieved at the 1% counting loss level.

Vacuum-tube decade. It is possible to build higher speed decade counters by using electron beams in a vacuum rather than gas tubes. Such a device is the E1T scale-of-ten, a specially designed vacuum tube incorporating an electron gun, deflection plates, and target with ten apertures (*6*).

In order to understand how this tube has stable states, consider the situation illustrated in Fig. 6. The beam is grazing the right edge of the sixth aperture in the target plate T. Part of the beam is going through the aperture and striking a fluorescent screen giving an external indication of the count while the rest of the beam is being collected by the target plate, causing a current to pass through resistor R_t. If the beam begins to wander to the right so that more current flows to the target plate, the additional voltage drop in R_t makes deflector D' more negative, forcing the beam back towards the slot. Conversely, if the beam drifts to the left, the current in R_t diminishes, making D' more positive, pulling the beam back to the edge of the aperture. This same reasoning applies to the beam in any slot, the mechanism being such as to "lock" the beam on the right edge of each aperture.

Counting is accomplished by applying fast positive pulses of just the proper amplitude to the other deflector D to "jump" the beam one slot to the left. The stabilizing feed-back from R_t is purposely slowed by capacitor C_t so as not to block these fast transitions from slot to slot.

The tenth count causes the beam to jump out of the ninth slot onto reset plate P. By means of external circuitry this current to the reset plate turns the beam off long enough for the target plate potential (and D') to rise sufficiently so that when the beam is turned on again it is directed onto the target plate to the right at the zero slot. The full beam current to the target plate discharges capacitor C_t, causing D' to shift the beam left where it locks onto the edge of aperture zero and is ready for the next count. Although the pulse pair resolution of the E1T is much better than the Dekatron, the average resolution is limited by the nine-zero (reset) transition.

Trochotron. The trochotron, another type of beam counting tube (*7*), avoids the necessity for reset by making use of a magnetic field to obtain a circular geometry similar to the Dekatron's. This tube consists of an axial line cathode surrounded by ten spade electrodes,

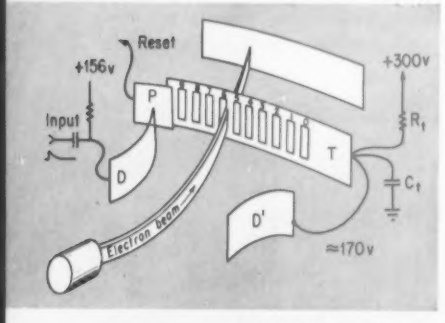


FIG. 6. VACUUM DECADE TUBE E1T is based on fact that beam "locks in" at any of ten positions by feedback to deflection plate D'. Stepping is accomplished by applying positive pulse to D

each connected to a positive supply voltage via its load resistor as in Fig. 6. A magnetic field perpendicular to the plane of the figure is supplied by an external permanent magnet. When the beam is first turned on electrons from the cathode, which would normally be accelerated to the spades, are deflected by the magnetic field into clockwise orbits about the cathode. The higher the supply voltage, the farther out these orbits extend, but as long as they are not allowed to reach the spades, no spade current is drawn.

Now suppose that the spade just counter-clockwise from target *5* is made momentarily less positive. This increases the magnitude of the electric field in the region between the spades opposite target *5*. Furthermore, the direction of the field shifts from being purely radial to include a clockwise tangential component. This new electric field pulls the orbiting electrons into the spade just made momentarily less positive. Spade current then produces a voltage drop in the spade resistor causing the active spade to be forced even more negative. This further increases the electric field causing the beam to move more clockwise until part of it is striking target *5*. The current to target *5* decreases the current available to the active spade preventing it from going further negative. Thus the beam is "locked" in such a position that its current is shared between the active spade and target *5*.

Counting is accomplished by momentarily pulsing the drive grids positive. This shifts the beam to the clockwise spade, dropping its potential and forcing the orbiting electrons to be deflected into a new stable beam in position *6*. Trochotrons can be made to count at very high speeds with resolving times less than 1 μsec and are widely used as the first decade in fast scalers (*8*).

Indicators

The need for fast scalers is rendering mechanical registers obsolete. For example, a 1 μsec scaler operating at a 5% counting loss requires the scaling factor provided by four electronic decades to reduce the counting rate to a point at which it can be handled by a mechanical register. Under these conditions the register is often dispensed with and two or three more electronic decades added to make up the required total count capacity.

We are thus faced with the problem of conjuring up something electronic to replace the nice, unambiguous indication of total count presented by a mechanical register. Solutions to this problem are provided for us in the case of the Dekatron and E1T which are both self-indicating.

The voltage swings on the trochotrons and vacuum-tube buggered binaries are large enough to allow the use of neon lamps or the newer glow number indicators such as the Nixie (*7*). These latter devices are multicathode gas tubes whose cathodes form the Arabic numerals.

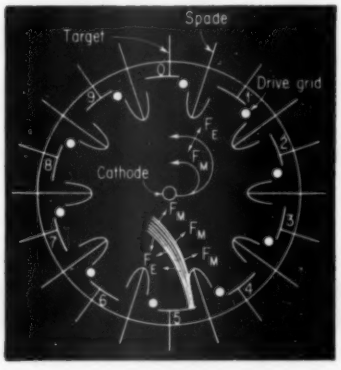


FIG. 7. TROCHOTRON uses a magnetic field to bend beam from cathode at center and lock in on appropriate target-spade combination. Counting is accomplished by pulsing drive grids positive, thus moving beam clockwise one step

The indicating problem is more difficult in the case of the transistor buggered binary. Special transistors must be used if enough voltage is available to operate neon tubes. Recently there have been some lower voltage indicating devices made available for transistors, but these are expensive since ten of them are usually required for each decade.

Printing scalers in which the count is printed out on a piece of paper are becoming more popular (*9, 10*). Transistor decades work well in these applications since indication other than the printed number is probably not required. The particular buggered binary system used in Figure 4 is convenient in this connection sine the flip-flop states correspond to the straight binary code.

Trends

The lack of relatively widespread use of scalers faster than 1-μsec pulse-pair resolution over the last five years is due to system limitations imposed by the popular use of NaI scintillation detectors. Since this phosphor requires about 1 μsec to emit all of its light, there is no need for faster scalers when using it. However, the recent increasing use of liquid and plastic scintillators will doubtless increase the demand for very fast scalers.

The memory capacitors of the conventional flip-flops (Fig. 1, right) ultimately limit the transition speed. By making use of delay lines as memory elements, it has been possible to design scalers with better than 100 mμsec pulse-pair resolution using standard tubes (*11*). Similarly fast circuits using surface barrier transistors have been constructed in which hole storage is used to advantage by providing memory of the direction of the transition (*12*).

Besides transistors, another solid-state device beginning to find some use in scalers is the magnetic core, and any review would not be complete without mentioning them (*13*).

Furthermore, as the transistor manufacturers begin to search for more exotic transistors, we might see the development of a solid state analog of the gas tube Dekatron and the vacuum-tube trochotron. Such devices might consist of a plurality of junctions located circularly around the edge of a common disc of base material, using diffusion coupling to transfer from junction to junction.

* * *

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12. E. Baldinger, P. Santchi, *Nuc. Instr.* **2,** 128 (1958)
13. E. Franklin, J. B. James, *Nuc. Instr.* **2,** 348 (1958)

An International Survey of Photomultipliers for

Allen B. DuMont Laboratories, Inc. (U.S.)

Tube number:	6365	6362	6935	6291	6467	7065	6292[2]	6363[3]
Number of stages:	6	10	10	10	10	10	10	10
Number of pins:	9			12	12	12	14	14
Dynode type:	box	box	box	box	box	box	box	box
Dynode material:	AgMgOCs	AgMgOCs	SbCs	AgMgOCs	AgMgOCs	SbCs	AgMgOCs	AgMgOCs
Cathode material:	SbCsO	SbCsO	SbCsO	SbCsO	SbCsO	SbCsO	SbCsO	SbCsO
Cathode diameter (in.):	½	½	½	1¼	1	1¼	1½	2½
Window diameter (in.):	¾	¾	¾	1½	1¼	1½	2	3
Max. tube diameter (in.):	⅞	13/16	13/16	19/16	1½	19/16	2¼	3 3/32
Seated tube height (in.):	2 3/16	4⅞[1]	4⅞[1]	4¼	4	4¼	4⅞	5⅜
Avg. cathode sensitivity (μa/lumen):	50	50	50	60	60	60	60	60
Cathode-to-dynode voltage (v):	210	210	210	210	210	210	210	300
Dynode gain:	4.0	3.5	4	4.5	4.5	6.0	4.5	5
Over-all voltage (v):	1,000	1,150	1,150	1,150	1,150	1,000	1,150	1,150
Over-all sensitivity (amps/lumen):	0.15	7.5	15	13	13	45	13	13
Dark current (μa):	<10	<0.05	<0.1	<0.05	<0.05	<0.05	<0.05	<0.05
Max. linear output current (ma)								
—high gain:	5	5	5	5	5	n.a.	5	5
—high current:								

EMI Electronics, Ltd. (U.K.)

Tube number:	9536B[4]	9536S	9578B	9578TA	9579B	9524B[5]	9524S	6097B[6]
Number of stages:	10	10	10	10	10	11	11	11
Number of pins:	14	14	14	14	14	14	14	15
Dynode type:	vane	vane	vane	vane	vane	box	box	vane
Dynode material:	SbCs	SbCs	SbCs	SbNaKCs	SbCs	SbCs	SbCs	SbCs
Cathode material:	SbCsO	SbCs	SbCsO	SbNaKCs	SbCsO	SbCsO	SbCsO	SbCsO
Cathode diameter (in. or mm):*	1¾		2½	2½	4⅜	23	23	44
Window diameter (in. or mm):*	2 1/16		3 3/32	3 3/32	5	28.6	28.6	51
Max. tube diameter (in. or mm):*	2¼		3 3/32	3 3/32	5	28.6	28.6	51
Seated tube height (in. or mm):*	4⅞		5⅜	5⅜	6¾	112	112	112
Avg. cathode sensitivity (μa/lumen):	50	30	50	100	50	50	30	50
Cathode-to-dynode voltage (v):	150	150	300	300	450	150	150	150
Dynode gain:	5	4	6	4	6	6.5	6	5
Over-all voltage (v):	1,400	1,600	1,450	n.a.	1,450	1,100	1,200	1,400
Over-all sensitivity (amps/lumen):	50	50	50	n.a.	50	200	200	200
Dark current (μa):	0.008	0.001	0.02	n.a.	0.04	0.01	0.002	0.03
Max. linear output current (ma)								
—high gain:	10	n.a.	10	n.a.	10	5	n.a.	10
—high current:	50	n.a.	50	n.a.	50	10	n.a.	50
Rise time—high-current (mμsec):	6	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	7
Time spread (mμsec):	14	n.a.	n.a.	n.a.	n.a.	~20	n.a.	14

* Dimensions <10 are in.; >10, mm.

[1] Over-all length.

[2] Also available with fuzed-quartz face plate as K1306.

[3] Also available with fuzed-quartz face plate as K1758.

[4] Also available with fuzed-quartz face plate as 9552B.

[5] Also available with fuzed-quartz face plate as 9526B; max. tube dia. is 30.5 mm.

By JOHN SHARPE, *EMI Electronics, Ltd., Hayes, Middlesex, England*

6364	7064	K1390	K1391	K1295	K1209	K1213	K1328	K1384	K1386
10	10	10	10	12	12	12	12	12	12
14	14	14	14	14	25	25	25	25	25
box	box	box	box	box	box	box	box	box	box
AgMgOCs	SbCs	SbCs	SbCs	AgMgOCs	AgMgOCs	AgMgOCs	AgMgOCs	AgMgOCs	AgMgOCs
SbCsO	SbCsO	SbCsO	SbCsO	SbCsO	SbCsO	SbCsO	SbCsO	SbCsO	SbCsO
4 3/16	1 1/2	2 1/2	4 3/16	1 1/2	4 3/16	2 1/2	14	11 1/4	19 1/4
5 1/4	2	3	5 1/4	2	5 1/4	3			
5 11 1/32	2 1/4	3 3/32	5 11 1/32	2 1/4	5 11 1/32	3 3/32	15 7/8	12 1/2	20 9/16
6 3/4	4 7/8	5 3/8	6 3/4	6	7 3/4	6 3/8	13 1/4	11 3/4	17 17/32
60	60	60	60	60	60	60	40	40	40
400	210	300	400	210	300	210	400	400	400
5	6.0	6.5	6.5	4.5	4.5	4.5	n.a'	n.a.	n.a.
1,150	1,000	1,150	1,150	1,250	1,250	1,250	1,650	1,650	1,650
13	45	45	45	12	12	12	32	32	32
<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.5	<0.5	<0.5
5	5	5	5	5	5	5	5	5	5

6097E	6097F	6097G	6097S	9530B[7]	9531B	9545B[8]	9558B	9514B[9]	9514S
11	11	11	11	11	11	11	11	13	13
15	15	15	15	15	15	15	20	15	15
vane	vane	vane	vane	vane	vane	vane	vane	vane	vane
SbCs	SbCs	SbCs	SbCs	SbCs	SbCs	SbCs	SbNaKCs	SbCs	SbCs
SbCsO	SbCsO	SbCsO	SbCs	SbCsO	SbCsO	SbCsO	SbNaKCs	SbCsO	SbCs
44	44	44	44	111	75	250	44	44	44
51	51	51	51	127	91	310	51	51	51
51	51	51	51	127	91	310	51	51	51
112	112	112	112	170	155	360	140	121	121
55	60	55	30	50	50	40	100	50	30
150	150	150	150	450	300	600	150	150	150
5.5	5.5	5.5	4.5	6	6	6	4	5	4.5
1,050	1,200	1,300	1,600	1,500	1,400	2,000	1,700	1,400	1,700
200	50	200	200	200	200	200	200	2,000	2,000
0.02	0.1	0.02	0.002	0.25	0.15	1.0	0.003	0.2	0.02
8	n.a.	9	n.a.	n.a.	n.a.	n.a.	n.a.	8	n.a.
50	n.a.	50	n.a.	n.a.	n.a.	n.a.	n.a.	50	n.a.
7	n.a.	7	n.a.	n.a.	n.a.	n.a.	n.a.	8	n.a.
14	n.a.	14	n.a.	n.a.	n.a.	n.a.	p.a.	16	n.a.

[6] Also available overcapped with diheptal base as 9584B.
[7] Also available overcapped with diheptal base as 9583B.
[8] Cathode connection through side.
[9] Also available with fused-quartz face plate as 6255B; max. tube dia. is 51.5 mm.
[10] Also available with fused-quartz face plate as 51UVP.

Table continued on next page

An International Survey of Photomultipliers for

Fernseh, Gmbh. (Germany) → Lab. of Electronics and Applied Physics (France)

Tube number:	FS9A	FS9F20	FS9F20S	150AVP	52AVP	51AVP[10]	53AVP[11]	54AVP
Number of stages:	9	9	9	10	10	11	11	11
Number of pins:	12	12	12	12	13	12	14	14
Dynode type:	linear	linear	linear	linear	linear	linear	linear	linear
Dynode material:				AgMgOCs	AgMgOCs	AgMgOCs	AgMgOCs	AgMgOCs
Cathode material:	SbCsO	SbCsO	SbCsO	SbCs	SbCs	SbCs	SbCs	SbCs
Cathode diameter (mm):	25	25	25	32	20	32	44	111
Window diameter (mm):	35.7	36	36	40	25	40	55	130
Max. tube diameter (mm):	35.7	36	36	40	25	40	57	130
Seated tube height (mm):	120	120	120	110	130	110	128	210
Avg. cathode sensitivity (μa/lumen):	60	70	105	50	30	50	50	50
Cathode-to-dynode voltage (v):	130	130	130	>180	>180	>180	>180	>180
Dynode gain:	6	3.5	3.5	n.a.	n.a.	n.a.	n.a.	n.a.
Over-all voltage (v):	1,000	1,000	1,000	1,800	1,800	1,800	1,800	2,000
Over-all sensitivity (amps/lumen):	120	1	1	300	30	500	500	500
Dark current (μa):	<0.1	n.a.	n.a.	<0.05	<0.1	<0.025	<0.05	<0.05
Max. linear output current (ma)								
—high gain:	10	10	10	30	5	30	30	30
—high current:	n.a.	n.a.	n.a.	100	10	100	100	100
Rise time—high-current (mμsec):	n.a.	n.a.	n.a.	4	n.a.	4	4	n.a.
Time spread (mμsec):	n.a.	n.a.	n.a.	6	n.a.	6	6	n.a.

20th Century Electronics, Ltd. (U.K.)

Tube number:	VMP11/44/A	VMP11/44/B[16]	VMP11/44/C	VMP11/44/S	VMP11/111	VMP11/170	VMP13/44
Number of stages:	11	11	11	11	11	11	13
Number of pins:	15	15	15	15	15	15	15
Dynode type:	vane	vane	vane	vane	vane	vane	vane
Dynode material:	SbCs	SbCs	SbCs	SbCs	SbCs	SbCs	SbCs
Cathode material:	SbCsO	SbCsO	SbCsO	SbCs	SbCsO	SbCsO	SbCsO
Cathode diameter (in. or mm):*	44	44	44	44	111	170	44
Window diameter (in. or mm):*	51	51	51	51	127	190	51
Max. tube diameter (in. or mm):*	51	51	51	51	127	190	51
Seated tube height (in. or mm):*	111	111	111	111	150	195	121
Avg. cathode sensitivity (μa/lumen):	55	50	>20	30	40	40	55
Cathode-to-dynode voltage (v):	150	150	150	150			150
Dynode gain:	5	5	5	5			5
Over-all voltage (v):		1,200	<1,500	1,200	<1,600	<2,000	1,400
Over-all sensitivity (amps/lumen):		200	20	200	200	200	2,000
Dark current (μa):		0.03	<0.05	0.003	<0.1	<0.5	0.05
Rise time—high-current (mμsec):							
Time spread (mμsec):							

* Dimensions less than 10 are in.; greater than 10, mm.

[11] Also available with fuzed-quartz face plate as 53UVP.

[12] Also available with fuzed-quartz face plate as 56UVP.

[13] Also available with fuzed-quartz face plate as 55UVP.

[14] Also available with UV transmitting glass as BMUV10/14.

[15] Also available with quartz window as BMQ11/23; max. tube

Scintillation Counting *(Continued)*

20th Century Electronics, Ltd. (U.K.)

57AVP	56AVP[12]	55AVP[12]	58AVP	FMK/5R/10	BMS10/14/B[14]	BMS10/14/C	BMS11/23/A	BMS11/23/B[15]	BMS11/23/S
11	14	15	16	5	10	10	11	11	11
14	20	20	20	15	13	13	14	14	14
linear	linear	linear	linear		box	box	box	box	box
AgMgOCs	AgMgOCs	AgMgOCs	AgMgOCs	SbCs	SbCs	SbCs	SbCs	SbCs	SbCs
SbCs	SbCs	SbCs	SbCs	SbCsO	SbCsO	SbCsO	SbCsO	SbCsO	SbCs
200	42	44	110		14	14	23	23	23
230	55	55			19	19	29	29	29
230	55	55			19	19	29	29	29
300	170	152			90	90	112	112	112
50	50	50	50	50	55	>20	60	60	30
>250	>250	>180	500		150	150	150	150	150
n.a.	n.a.	n.a.	n.a.		6	6	6	6	6
n.a.	3,500	2,000	n.a.	2,500	1,200	<1,600		1,000	1,100
300	>5,000	>5,000	>5,000	0.3	150	15		200	200
<1	<5	<5	<35		0.05	<0.1		0.05	0.005
30	100	30	100		5	5	5	5	5
100	300	100	300	400					
n.a.	2	4	2						
n.a.	0.3	6	1						

Radio Corp. of America (U.S.)

C7204	6199	2020[17]	6342A	6655A	6903[19]	7326	6810A	7264	7265	7046[21]
9	10	10	10	10	10	10	14	14	14	14
11	12	14	14	14	14	14	20	20	20	21
linear	cage	cage	cage	cage	cage	linear	linear	linear	linear	linear
CsSb	CsSb	AgMgOCs	AgMgOCs	CsSb	CsSb	AgMgOCs	AgMgOCs	AgMgOCs	AgMgOCs	AgMgOCs
SbCsO	SbCsO	SbCsO	SbCsO	SbCsO	SbCsO	SbNaKCs	SbCsO	SbCsO	SbNaKCs	SbCsO[22]
½	1¼	1½	1 1/16	1 1/16	1⅝	1 1/16	1 1/16	1 1/16[20]	1 1/16	4 7/16
	1 9/16	2	2	2	2	2	2	2[20]	2	5
2 5/32	1 9/16	2 5/16	2 5/16	2 5/16	2 5/16	2⅜	2⅜	2⅜	2⅜	5¼
3½	3⅞	4⅞	4⅞	4⅞	5⅝	5 27/32	6 11/16	6 11/16	6 11/16	9¾
40	45	50	80	55	60	150	70	70	150	60
n.a.	165	208	208	165	165	300	216	216	200	1,200
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
1,000	1,000	1,250	1,250	1,000	1,000	1,800	2,000	2,000	2,400	2,800
4	27	6	14	50	24	22.5	875	875	1,400	180
0.004	0.019	0.003	0.008	0.065	0.022	0.009	0.39	0.39	0.27	0.34
n.a.	n.a.	2–5[18]	3	3	n.a.	2.5	3	3	3	n.a.
n.a.	6	n.a.	4	4.5	8	3	3	1	3	4

dia. is 31 mm; window dia. is 31 mm; cathode dia. is 23 mm.

[16] Also available with quartz window as VMQ11/44.

[17] Low-resistance cathode.

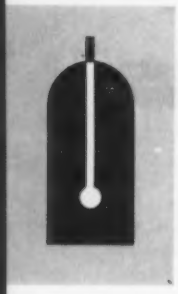
[18] At 1,500 v.

[19] Fuzed-silica face plate.

[20] Curved.

[21] Cathode connection through side.

[22] UV transmitting glass.



Diversity of design provides G-M tubes for many uses: hollow anodes for 4π and liquid-flow counting, compact coincidence units and integrator tubes for inexpensive, reliable monitors and alarm devices

G-M COUNTERS

By K. VAN DUUREN, A. J. M. JASPERS and J. HERMSEN
Philips' Research Laboratory, Amsterdam, The Netherlands

G-M TUBE DEVELOPMENT, particularly with the advent of the rare-gas–halogen filling, has led to better counting characteristics and more flexible design permitting greater adaptability to diverse applications.

The halogen admixture does not deteriorate with use as do organic quenching agents. At the same time, halogen counters provide comparable deadtimes and delay times and greater freedom in choice of geometry.

Specialized counters have been developed for a number of applications. Figure 1 pictures various designs. Current G-M tube technology is discussed in this article by first outlining present ideas of the mechanisms of Geiger discharges and then describing the newer designs.

G-M counters can be classified as self-quenched and non-self-quenched counters. Representative of the first group is the argon-alcohol counter. With this type of counter, the initial discharge is quenched by the action of the positive space charge, while spurious afterpulses are prevented by the action of the quenching agent. In non-self-quenched counters, the same quenching mechanisms may be present, but they are not sufficient to provide effective quenching (*1*). A large series resistor or an external quenching circuit is then required to keep the counter voltage low for an interval after the discharge has started. The argon-hydrogen counters belong to this group (*1*).

Counters filled with a mixture of rare gases and halogens, e.g., Cl_2 and Br_2, are self-quenched only near their starting voltage. At higher overvoltages, the halogen counter no longer operates as a self-quenched counter. Compared with the older types of gas counters (*1*), halogen counters require relatively small resistance values for adequate quenching, i.e., 1–10 Meg. As a consequence, the deadtime of halogen counters is of the same order of magnitude as that of organic-quenched counters.

The behavior of these counters is strongly influenced by the electron affinity of the halogens, which may have a detrimental influence on the efficiency. The effect of attachment is most serious at low overvoltages. Therefore, it is generally desirable to operate a halogen counter at high overvoltage, i.e., in the non-self-quenching region.

Delay times are generally rather long for halogen admixtures (*2*, *3*);

Where G-M Counters Are Used

Four types of radiation detectors are in current use: ion chambers and proportional, G-M and scintillation counters. The applicability of each is determined by its efficiency, counting life, reproducibility, associated circuitry, ruggedness, size, weight and cost.

In contrast to the proportional and scintillation counters, the G-M counter is a nondiscriminating device—the plateau curve is independent of radiation type and energy. Thus, interpretation of results is straightforward. This is advantageous since, for the majority of applications, a discriminating device is not needed because only one radioisotope is used. Furthermore, with radioisotopes and detection coming increasingly into the hands of non-physicists, there is an increasing demand for simple, reliable instruments—conditions well satisfied by halogen G-M counters, particularly in combination with transistor circuits.

A number of applications where G-M counters are advantageous are:

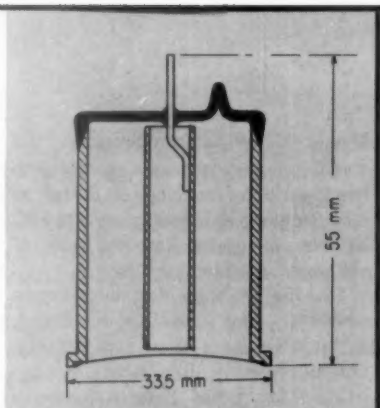
Beta measurement of solid samples. Efficiency is comparable with gas-flow proportional counter, but without the awkward filling system. Dimensions are small compared with a scintillation counter, keeping lead-shield weight low. Background counting rate is low due to low gamma sensitivity. Although deadtime is large, a high counting rate is not needed for sufficient accuracy.

Low-level detector. Small size and low gamma sensitivity make it ideal. Very compact anticoincidence arrangements are possible.

Portable dose-rate meters. Gamma efficiency is large enough for tolerance-level measurements or a factor of ten lower. Satisfactory uniformity of response can be achieved by appropriate shielding and filtering. Advantages are small size, ruggedness and simplicity.

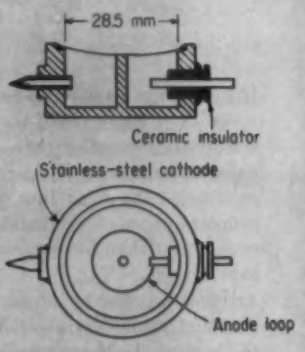
Thickness gages. Counters can be designed with a 10-μsec deadtime. One or more counters in parallel make possible a short time constant with adequate accuracy. Source strength can generally be smaller than that required for an ion chamber.

4π gamma counting. Although scintillation counters have better efficiency, sources down to 0.001 μc can be counted. Precision is good enough to permit use as a secondary standard for source calibration.

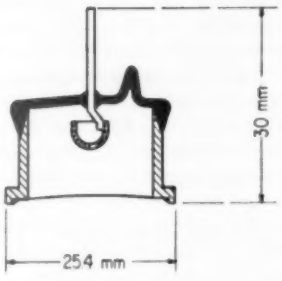


Ⓐ Thick-anode beta counter

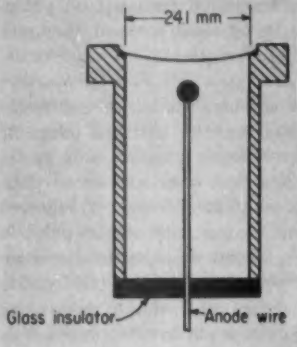
Ⓑ Experimental double counter



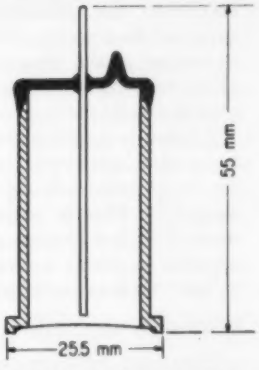
Ⓒ Pancake beta counter



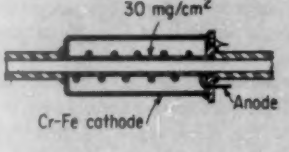
Ⓓ Spherical-anode beta counter



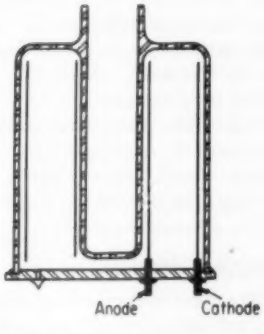
Ⓔ End-window beta counter



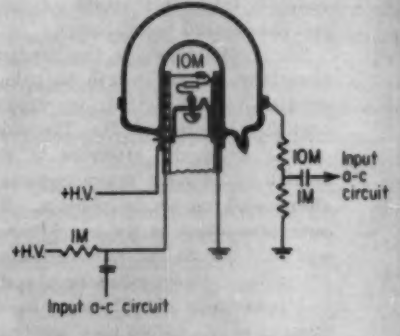
Ⓕ End-window beta counter



Ⓖ Hollow-anode liquid beta counter

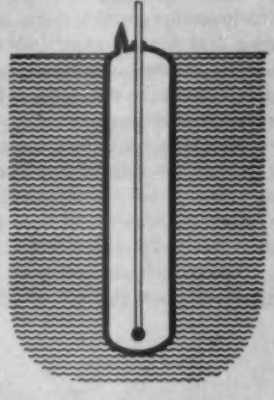


Ⓗ 4π liquid gamma counter



Ⓘ Anticoincidence counter

Ⓙ All-glass liquid counter



Ⓚ All-glass liquid counter

FIG. 1. G-M COUNTER DESIGNS for various applications. (A) Philips end-window β-counter 18505. (B) Double counter for end-effect study; counter B kept at constant voltage. (C) Anton 1007 pancake β-counter. (D) Prototype of Philips 18515 spherical-anode β-counter; metallic layer covers inside of 1.5–2 mg/cm² mica window. (E) Mullard MX 113 end-window β-counter. (F) Philips 18505 end-window B counter. (G) Hollow-anode liquid β-counter. (H) 4π gamma liquid counter. (I) Anticoincidence arrangement of low-background β-counter with guard counter. (J) and (K) All-glass liquid counters

however, for neon-argon-halogen mixtures, these times are of the order of a factor of 10 smaller than for argon-halogen mixtures. Under favorable conditions, the delay time for halogen counters becomes comparable with or even better than for organic-quenched counters.

Halogen counters can be made with counting properties that are superior to organic G-M counters. An important advantage of the halogen counter is that the quenching agent is not deteriorated by the discharge. Moreover, the greater freedom of choice for the geometry is an important advantage of the neon-argon-halogen filling over the conventional organic-quench filling (*4*).

A difficulty is that the materials have to be chemically inert, especially for the ionic bombardment during the discharge. This is particularly true where very low halogen pressures are required to obtain a sensitivity close to unity for beta particles and mesons.

Discharge Mechanism

The Geiger discharge is not confined to the region of the gas volume where the primary avalanches are formed. Photons created in these avalanches can cause photoionization at some distance from their point of origin and thus spread the discharge.

The propagation of the discharge along the counter length in halogen counters is like that in organic-quenched counters (*5*, *6*). The energy of the avalanche electrons is high enough to produce many metastable atoms and resonance photons. The main absorption of the uv photons is probably due to the noble-gas atoms (*7*). These photons can be absorbed and re-emitted several times by the rare-gas atoms before they are finally absorbed by a halogen molecule, causing photoionization. The photoelectron can start a secondary avalanche, and in this way the discharge spreads along the wire.

For halogen pressures as high as a few mm Hg and rare-gas pressures higher than 200 mm Hg, the discharge starts over a limited region along the wire. The discharge spreads in both directions along the wire, while it extinguishes at the spot where it started. In this way, two "burning" regions move along the wire, leaving a dense ion sheath on the surface of the anode at those parts where the discharge has gone out. The shape of this strongly differentiated electrical pulse is influenced by the place of irradiation of the counter (*6*). With halogen counters, this characteristic disappears at a low halogen pressure (*8*), which means that the discharge has spread over the whole length of the counter before being extinguished at the point where it started.

This picture of halogen-counter discharge is true only just above threshold. At higher overvoltages, another mechanism sets in. At a given voltage V_t (the transition voltage), all pulses appear to be double when they are strongly differentiated. The overvoltage $(V_t - V_s)$, where V_s is the starting voltage, at which this occurs is strongly dependent on the cathode diameter and the halogen pressure and varies between a few volts and more than 100 volts. Van Zoonen (*9*) showed that the second part of the pulse is due to a second phase of the discharge taking place between the positive-ion space charge and the cathode—the second pulse is not to be confused with the well known afterpulses that can occur after the deadtime. This mechanism of double pulses has almost no influence on the plateau characteristics because the separation of the pulses is only of the order of a microsecond at the transition voltage and decreases rapidly at higher overvoltage. At about 100 volts above V_t, the two pulses become one.

Below the transition voltage, the discharge is quenched by the space charge alone; above the transition voltage, the quenching is mainly due to the external circuit.

Starting Voltage

The combination of a neon or neon-argon mixture and a very small admixture of halogen makes it possible to construct counters with starting voltages as low as 250 volts (*10*). These low operating voltages are advantageous for portable instruments. Penning (*11*) showed that breakdown voltage is lowered when the ionization potential of the admixture is lower than the lowest metastable level of the rare-gas component of the mixture.

A similar lowering of the starting voltage, though not as large as for the neon mixtures, was found for argon-bromine and krypton-iodine mixtures (*12*). The effect only occurs at halogen pressures lower than about 0.1 mm Hg; at higher halogen pressures, the starting voltage increases again due to the lowering of the electron energy as a consequence of inelastic impacts with halogen molecules and the loss of electrons by attachment.

Starting voltage for thick-anode counters. The ionization coefficient, α, for neon-argon-halogen mixtures is not appreciably influenced by the halogen for partial halogen pressures up to 1% if the halogen pressure is lower than the argon pressure (*13*). From the published values of α for neon-argon mixtures (*14*), one can deduce that, especially for neon-argon-halogen mixtures, the active volume is no longer confined to the immediate neighborhood of the anode. This means that the assumptions used by Trost (*15*) and Werner (*16*) for the derivation of the formulas for the starting voltage are no longer valid in this case, especially for large-anode diameters.

For the latter case, a simple relation between the starting voltage and the counter parameters can be derived:

$$A = \exp ap\phi \int_{\frac{a}{b}\phi}^{\phi} (\alpha/p)(E/p)^{-2} \, d(E/p) = 1/\gamma \quad (2)$$

where A = gas amplification factor; a = anode radius; b = cathode radius; p = pressure in mm Hg; E = electrical field strength in volt/cm; α = ionization coefficient; $\phi = (E/p)_{max} = (b/a)(E/p)_{min}$ for $V = V_s$. Equation 2 gives, for a given value of b, the relation between a and E/p at the anode surface at the Geiger threshold.

For the neon/argon mixture $\frac{1}{10}^{-3}$, we make the approximation $\alpha = \text{const.} \times E$. Moreover, we assume γ to be independent of E/p. Under these conditions, Eq. 2 can be simplified and one can deduce that ϕ shows an extremum for log $(b/a) = 1$. In effect, this extremum appears to be a minimum. This agrees reasonably well with the results of experiments that are shown in Fig. 2. At four different values of b, a minimum is found at about $a = b/e$. The minimum values of $(E/y)_{max}$ were all between 4.9 and 9.4 volts/cm/mm Hg.

Charge per Pulse

The behavior of the charge per pulse as a function of the counter voltage V and the impedance connected to the anode is shown for a Philips 18506

counter (see Fig. 1A) in Figs. 3 and 4.* The effects can be summarized as follows:

1. In the lowest voltage region, the amount of charge is completely independent of the anode impedance, but increases linearly with the overvoltage ($V - V_s$). This is the same behavior found for organic self-quenched counters.

2. At a rather well defined voltage (approximately the transition voltage V_t), the curves start to diverge.

3. Above V_t, the counter becomes non-self-quenching.

4. Curves of charge Q for a shunting capacitance (C_{sh}) equal to 10 $\mu\mu$f show a phenomenon that is very typical of halogen counters. A rather sharp bend of the graph occurs at V_t. Here the counter voltage drops rather far below V_s. Above V_t, Q increases linearly with ($V - V_r$); V_r, the rest voltage, may be 100 volts or more below V_s. Under these conditions, the discharge assumes the characteristic of a glow discharge. At still higher values of C_{sh}, a streamer-like mechanism sets in, which can be easily verified by visual observation of the discharge in a darkened room.

5. The curves for different series resistors show that the amount of electrical charge transferred per pulse is little affected by the value of the series resistor.

Van Zoonen found that $V_t - V_s$ depends greatly on the nature and the amount of the halogen component. The anode diameter is important, too. In the case of the Philips 18506, V_t is shifted below the straight section of the plateau curve with a thick anode (8-mm diameter), while, with a 1-mm-diameter anode, V_t should fall about in the middle of the plateau.

* Some of the measurements of this article refer to counters manufactured in our laboratory; they might differ slightly from those commercially produced.

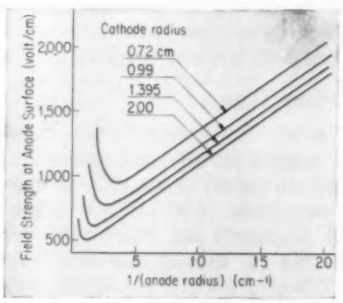


FIG. 2. FIELD STRENGTH at anode surface at starting voltage as function of 1/(anode radius) for various values of cathode radius (r_c). Partial pressures (mm Hg) of gas filling are Ne, 100; A, 0.1; Br_2, 0.065

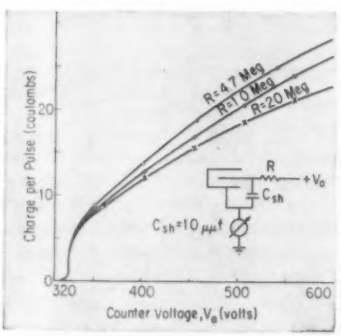


FIG. 3. CHARGE PER PULSE as function of counter voltage for various values of shunt capacitance (C_{sh})

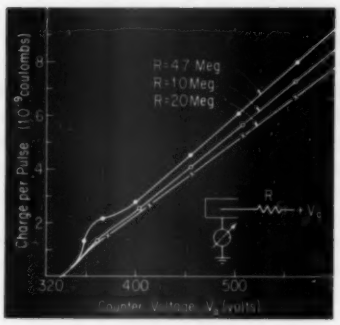


FIG. 4. CHARGE PER PULSE as function of counter voltage for various values of series resistance (R)

Deadtime

Although the halogen counter behaves like a self-quenched counter below V_t, the discharge mechanism differs considerably as far as the deadtime (interval after response to one signal during which system is unable to respond to another) is concerned. Figures 5 and 6 show that the deadtime for halogen counters increases monotonically below V_t. However, for organic counters, deadtime, which is determined by the movement of a thin uniform space-charge sheath, is at a maximum at V_s and decreases for higher voltages (*17*).

Above V_t, the halogen counter operates as a non-self-quenched counter. Figures 5 and 6 show that in this region, in most cases, the deadtime decreases at higher overvoltage. This decrease in deadtime can be explained as follows: If no space charge were present, the counter voltage should recover as

$$(V_w - V) = (V_w - V_r)e^{-t/RC}$$

where V_w = working voltage; V_r = counter voltage at the moment the pulse reaches its maximum amplitude; R = series resistance; C = total capacitance of the anode and attached circuitry. In this case, the deadtime should be given by $t_d = RC \log (V_w - V_r)/(V_w - V_s)$.

From the foregoing, it follows that whether the deadtime is determined by the movement of the space-charge sheath or whether it is determined by the external impedance connected to the counter anode, it should always be a monotonically decreasing function of the overvoltage. From Figs. 5 and 6, this is not the case with counter 18506. The increase in deadtime could be partly explained by the variation of V_r with the overvoltage. Van Zoonen has found that in certain cases V_r decreases at higher overvoltages. This mechanism, however, can not explain the behavior of the deadtime in the region just above V_s. Another mechanism must be responsible for the behavior in this region, and this may be the nonuniform distribution of the positive-ion space-charge sheath along the counter length, i.e., enhancement of the sheath length with increasing overvoltage. In this case the complete picture of the variation of the electrical field during the transit time of the positive-ion sheath is so complex that an exact calculation seems to be unattainable. From the general trend of the curves, however, one can deduce in a qualitative way which effects are dominant in the region under consideration.

From the experimental results, a

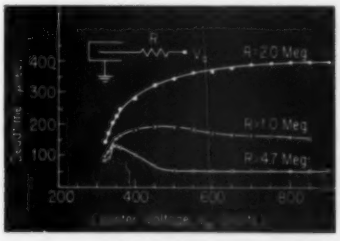


FIG. 5. DEADTIME as function of counter voltage (V_0) for various values of series resistance (R)

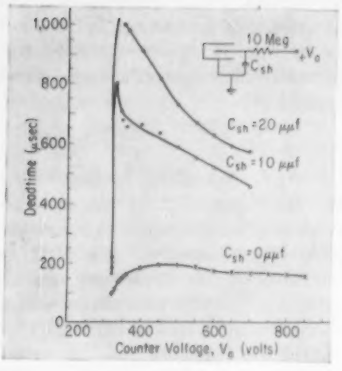


FIG. 6. DEADTIME as function of counter voltage (V_o) for various values of shunt capacitance (C_{sh})

few conclusions of practical use may be drawn:

1. Low deadtimes are achievable at high overvoltages.

2. The parasitic capacitance of the wiring greatly influences the deadtime. It is therefore advisable to connect the series resistor directly to the anode connector.

3. At high counting rates, the average counter voltage decreases due to the voltage drop over the series resistor. The deadtime, therefore, first increases when the counting rate increases, decreases when the average voltage passes the maximum of the t_d-vs-V curve and, when the average voltage is about equal to V_o, becomes very small. It is clear that at high counting rates the pulse size decreases too. Thus, to have the full benefit of the small deadtime at high counting rates, it is necessary to choose the input sensitivity of the scaler sufficiently high, i.e., 0.1 volt or better.

Counting Efficiency

The strong electron affinity of the halogens can greatly influence the detection efficiency of halogen counters. Electrons that are captured by halogen molecules are lost to the gas multiplication process because detachment is impossible. Franklin and Loosemore (*18*) compared the efficiency of halogen counters ($2a$ = 0.1 mm; $2b$ = 25 mm; neon pressure = 200 mm Hg; argon pressure = 0.2 mm Hg) with that of an organic-quenched counter and found counting losses linearly increasing with the bromine pressure, resulting in a loss amounting to 27% at a bromine pressure of 2 mm Hg.

Shinohara and Akutsu (*19*), measuring a P^{32} source with an end-window beta counter, found efficiencies of 62% for 300-mm-Hg argon and 0.4-mm-Hg Br_2 and 22% for 435-mm-Hg argon and 5.5-mm-Hg Br_2. These values show how halogen pressure lowers detection efficiency. The loss of efficiency is more unfavorable for argon-bromine gas fillings than for neon-argon-bromine mixtures (*19*).

The probability that an electron drifting over the distance dr is captured is given by

$$\left(h\frac{c_1\sigma_1 p_1}{\lambda\sigma p v}\right)dr$$

where h = fraction of the collisions with bromine molecules that results in capture; c_1 = mean electron velocity; λ = mean electron free path; σ_1 = collision cross section of halogen molecule; σ = collision cross section of rare-gas atom; v = electron drift velocity; p_1 = halogen pressure; p = rare-gas pressure.

Although the various quantities are not known individually, Shinohara's and Akutsu's experiments (*19*) demonstrate that for the argon-bromine mixture the formula can be simplified to

$$[10.6p_1/(E/p)]\,dr \qquad (p_1 \text{ in mm})$$

Though these calculations can not be very accurate, the order of magnitude of the effect is right. This shows how serious the influence of attachment is at halogen pressures of 1mm Hg. Only a very small fraction of the electrons that are formed near the cathode will reach the active volume.

From this it follows that E/p should be as high as possible at the cathode surface to reduce the counting loss caused by attachment. Since the cathode diameter is determined by the window diameter, the anode radius is the only remaining parameter of the geometry. A thick anode of 8 mm, such as that in the Philips 18506, increases E/p_{cath} by a factor of 5.5 compared with a 0.1-mm anode at the same operating voltage.

A second important advantage of the combined use of a large anode diameter and the low-voltage neon-argon-halogen filling is that the field strength is sufficiently high throughout the counter volume to cause ionization at every point along the electron path. Under the operating conditions of the 18506 tube, the maximum mean free path for ionization is of the order of 1mm, which is considerably less than the cathode radius. Under such conditions, the electron takes part in the multiplication process without crossing a passive volume, thus considerably decreasing the probability of attachment.

Experimental evidence on the effect of the various factors influencing the efficiency is given in the later section on flat-window beta counters.

Delay Time

Delay times (time from passage of ionizing particle until pulse reaches a given value) of the order of 6 μsec were found for halogen counters by Loosemore and Sharpe (*2*). Van Zoonen (*3*) showed that delay times between a fraction of a microsecond and 100 μsec cannot be explained by negative-ion formation but are due to a slow multiplication process. His results can be summarized as follows:

1. Delay time is inversely proportional to overvoltage.

TABLE 1—Effect of Beta-Counter Design

Counter number	*Description*	*Window diameter (mm)*	*Counter voltage (volts)*	*Counting rate (cps)*
I	Cathode shell, gas filling identical to Philips 18505; anode diameter 1 mm (see Fig. 1F)	19.8	650	53.5
II	Like counter I except 5-mm anode diameter	19.8	650	55.8
III	Philips 18515 (Fig. 1D)	19.8	650	58.6
IV	Cathode, anode, gas filling same as Philips 18506; mica window externally coated with aquadag (see Fig. 1A)	27.8	650	67.6
V	Like counter IV, but window uncoated	27.8	650	63.8
VI	Anton 1007 (Fig. 1C)	28.6	800	61.5
VII	Mullard MX 123 (Fig. 1E)	24.1	650	52.5

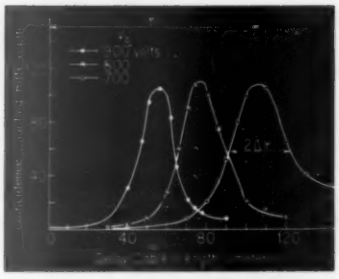


FIG. 7. DELAYED-COINCIDENCE COUNTING-RATE CURVE for Philips tube 18516 for various counter voltages. Data obtained with 1-meter clipping cable; 1 meter = 3.75×10^{-3} μsec (τ = average delay; $\Delta\tau$ = delay spread)

2. Neon-filled counters are much faster than argon-filled counters.

3. Thick anodes give shorter delays than thin anodes.

4. Delay time decreases at higher halogen pressures.

These phenomena can be satisfactorily explained by the time delay of the secondary avalanches with respect to the primary avalanches. The secondary avalanches are initiated by absorption of resonance photons, and it is clear that a high halogen pressure will accelerate this process.

For conventional counters with thin anodes, a considerable part of the delay is caused by the passage of the electron through a passive volume before multiplication can take place. A thick-anode geometry is favorable for obtaining short delays for two reasons: (1) primary electrons start multiplication immediately after formation, i.e., there is no delay due to transit of a passive volume, (2) electron movement contributes appreciably to pulse formation.

In Fig. 7, a curve is shown of a few delayed coincidence measurements that were made with a combination of a 5-mm-diameter cylindrical counter and a Philips 18516 (a thin-window halogen counter similar to Fig. 1D, but having an 8-mg/cm² Cr-Fe window). A narrow beam of betas was directed so that it first traversed the small counter before hitting the 18516. Pulse shaping was done by delay-line clipping. A Milton coincidence circuit was used with an input sensitivity of ~1 volt. The delay of the small counter was negligible compared with that of the 18516. Comparison of these results with those of Picard and Rogozinski (*20*) for an argon-alcohol counter shows that, for spherical-anode halogen counters, the delay time and its spread are of the same order as for argon-alcohol counters, but at considerably lower counter voltages.

Plateau Slope, Length

Plateau characteristics of the 18506 counter are shown in Figs. 8 and 9.

Increasing shunt capacitance increases the plateau slope and shortens its length. The first effect can be partly explained by the variation of the deadtime along the plateau, which is shown in Figs. 5 and 6. Of course, the magnitude of this effect strongly depends on the counting rate. The second effect must be attributed to spurious counts, the probability of which increases when the amount of charge per impulse increases.

The most obvious cause of spurious counts is the secondary emission of electrons at the cathode surface by impact of positive ions. The work function, ϕ, of the cathode as well as the ionization potentials, E_i, of the halogen admixture determine the probability of this process. An excellent way to create a high work function is to oxidize the cathode surface (*21*), which also makes the cathode surface chemically inert to halogens (*22*). Fortunately, halogen gas itself further increases the work function (*23*). Intercomparison of the values for ionization potential energies for the halogen as found by Kuiper and Van Zoonen and the work function for various metallic oxides shows that for iodine ($E_i - 2\phi$) is negative and for bromine it is negative or slightly positive. When ($E_i - 2\phi$) is negative, secondary emission by positive-ion impact is out of the question as far as the halogen ions are concerned and can only occur with the noble-gas ions, which have much higher ionization potentials.

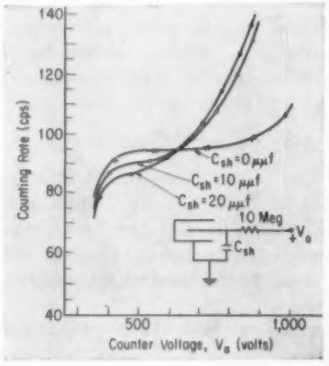


FIG. 8. PLATEAU CHARACTERISTICS for Philips tube 18506 for various values of shunt capacitance (C_{sh}); series resistance was 10 megohm in all cases

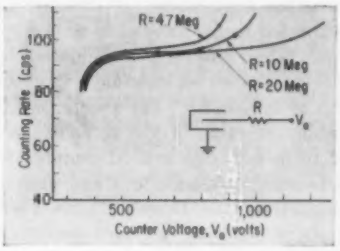


FIG. 9. PLATEAU CHARACTERISTICS for Philips tube 18506 for various values of series resistance (R)

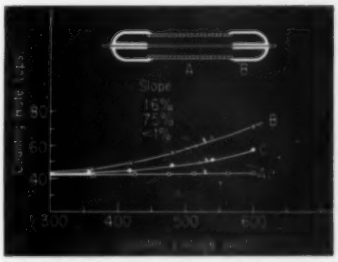


FIG. 10. PLATEAU CHARACTERISTICS with source positioned near counter (A and B) and at longer distance from counter (C); plateau slope is indicated along curves

It was pointed out earlier that, above the transition voltage, a very large fraction of the total charge forms at the outer part of the counter volume in the case of a high shunt capacitance. This may go so far, because of the short path length of the positive ions, that the transfer of charge from the neon ions to the halogen molecules is not complete, and some of the neon ions can then release secondary electrons from the cathode and thus cause an afterpulse. This explains the plateau shortening with larger shunt capacitance.

As shown in Fig. 9, a decrease in the series resistance shortens the plateau. Figures 3 and 4 show that the charge per pulse is only slightly dependent on the value of this resistor. Very likely, in this case, the metastable

atoms or molecules are the cause of the afterpulses. With smaller resistance values, the deadtimes become very short, perhaps only a few times the average lifetime of the metastables. The shorter the deadtime, the greater the probability that a few metastables will survive the deadtime.

To obtain a long plateau and a small plateau slope for a given counter, the parasitic capacitance of the wiring connected to the anode has to be kept low. This can be best achieved by placing the series resistance right on top of the anode. For general use, a minimum value of the series resistor of 10 megohms is a good compromise between deadtime length and plateau characteristics. In special cases where a short deadtime is more important than a very flat plateau, a lower value for R has to be chosen. How far R can be lowered largely depends on the counter geometry and the gas filling.

End Effects

When a counter similar to that of Fig. 10 is irradiated at its extreme ends by a point source, the plateau is always much steeper than when the source is positioned at the middle of the cathode shell (point A of Fig. 10). This phenomenon remains even when afterpulses are eliminated by means of the circuitry. Thus one is obliged to assume that the efficiency at the extreme ends of the counter is lower than in the middle.

One explanation could be that part of the electrons crossing the counter gas volume are not counted because all primary electrons formed by these electrons are captured. However, the situation is somewhat more complicated, and this is demonstrated by the following experiment:

In the double-counter arrangement of Fig. 1B, counter B is kept well above its starting voltage, i.e., 400 volts. A radioactive source is located near counter A in such a way that no direct radiation can hit counter B. Then, as the voltage of counter A is raised from zero, counter B starts to count when counter A is still 50 volts below its Geiger threshold. This demonstrates that, even in the proportional region of counter A, enough photons are produced to initiate a Geiger discharge in counter B. This situation is comparable with that encountered with the first counter. When the Geiger threshold is surpassed in the middle of the counter, the extremities are still in the proportional region. The higher the counter voltage is, the greater the probability becomes that the proportional discharges at the extremities will initiate a Geiger discharge in the middle of the counter. Thus, one can conclude that an incoming particle may not be counted, either because all primary electrons become attached to halogen molecules or because none of the active photons that are created in the primary avalanches reaches the central region of the counter to cause secondary avalanches.

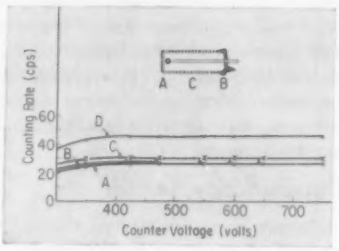


FIG. 11. PLATEAU CHARACTERISTICS for tube of improved design (compare with Fig. 10). Position D corresponds to uniform irradiation with parallel beam

The main reason that the end effect is more serious with halogen counters than with organic counters is that the range of the active photons is longer in the former. The primary disadvantage of this effect is that the plateau slope becomes unnecessarily large. However, after the end-effect mechanism was understood, its correction became a simple matter. The insulating glass at the extremities was charged to flat plates perpendicular to the axis. Plateau curves for the modified counter (Fig. 11) show the improved performance.

Flat-Window β-Counters

The end-window counter is widely used for beta counting. Most of the ion tracks, in this case, are formed immediately behind the window, which is usually an insulating material, e.g., mica.

The electrical field at the window end of the counter is distorted because of the decrease in the field caused by the electrode termination and because of the accumulation of electrical charges on the inside surface of the window. This distortion, occurring in that part of the counter where most of the ionization takes place, is highly undesirable because voltage fluctuations, change of counting rate and hysteresis effects can lead to fluctuations of the counting efficiency and plateau characteristics.

This difficulty has been solved by Anton (*23*) with the pancake G-M tube 1007 (Fig. 1C). The accumulation of surface charges is prevented by metallizing the inside of the mica window.

However, the elimination of the accumulated charges is only a partial solution. For halogen counters, a second requirement is that the electrical field strength at the cathode be high enough so that the mean free path length for ionization is considerably shorter than the mean free path for electron attachment. Multiplication by electron impact then occurs before attachment can take place.

Figure 1D shows a tube construction satisfying both conditions. Its features are

1. The anode is spherical or hemispherical with a diameter of about $\frac{1}{5}$ of the cathode diameter.

2. The window, stainless steel or mica, is made conducting on the inside by covering it with tin oxide or metal film.

3. The cathode length is considerably reduced.

The last feature makes this type of counter suitable for low-background

TABLE 2—Background Data with Hollow Guard Counter*

Shielding material	*Window diam. (cm)*	*Background (cpm)*	
		With guard counter in anti-coincidence	*Without guard counter in anti-coincidence*
10 cm iron	1.98	1.45	4.67
10 cm iron 5 cm lead	1.98	1.03	3.92
3.5 cm mercury 20 cm iron	1.98	0.77	3.57
2.5 cm "old" lead 20 cm iron	2.78	1.14	6.98

* Inner part of shielding is indicated first. The cosmic-ray contribution to background can be found by subtracting the third column from the last.

work because the cosmic-ray counting rate, as well as the counting rate due to stray gamma radiation, is lowered by the decrease in length.

To obtain an idea of the order of magnitude of these effects on counting efficiency, a series of measurements were done for various counters. A P^{32} source, in a 20-mm-diameter planchet, was placed at an identical distance from the counter windows. The counting rates thus obtained are given in Table 1. All measurements were made with a 10-megohm series resistor to prevent afterpulses. Comparison of the counting rates of counters I–III shows the improved sensitivity obtained by increasing the anode diameter and metallizing the inside of the window. The data for counters IV and V show that even an external conductive coating of the window aids in preventing accumulated charges on the window. For comparison, counting rates for the Anton 1007 and the Mullard MX 123 are given. The influence of high halogen content is also evident.

Special Liquid Counters

Increased anode diameter offers another advantage. The anode can be hollow and the radioactive source can then be placed within it, essentially providing a 4π counter. A thin-wall beta counter and a large gamma counter have been constructed in this way (*4*).

The thin-wall beta counter (Fig. 1G) is meant for measuring the activity of a flowing liquid, e.g., that of an ion-exchange column. The liquid flows through a thin glass tube having a 30-mg/cm² wall. The sensitive volume amounts to 0.4 cm³. In addition to the spiral anode, other possible constructions are three or four parallel stretched wires or a coarse grid. In all these constructions, the field distribution around the anode is somewhat unfavorable. For this reason, the plateau slope is 5% per 100 volts (for a 10-megohm series resistance), which is less favorable than that obtainable with a cylindrical anode.

Another type of liquid counter uses a hollow anode (Fig. 1H). The metal electrodes are completely enclosed in a glass envelope. A 20-cm³ glass sample tube, closed at one end, is inserted in the anode. For solid samples, this counter offers the advantage that the counting rate is not very sensitive

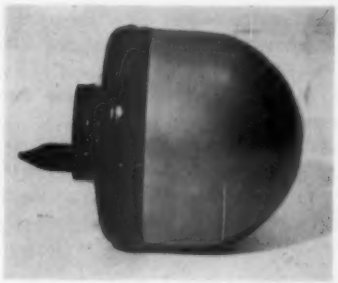


FIG. 12. HOLLOW-ANODE GUARD COUNTER for anticoincidence arrangement of beta counter; background is reduced by putting beta counter inside hollow anode of guard counter

to the sample position within the hollow anode. The almost ideal electrode configuration provides good electrical characteristics. With a series resistance of 5.6 megohms, the plateau has a slope of 2% per 100 volts and a length of about 400 volts. The working voltage can be chosen in such a way that the deadtime is <200 μsec. The counting rate for a 1-μc I^{131} source in the center of the hollow anode is 3,200 cpm, while the background is <100 cpm in a 5-cm lead shield.

A dip counter (Figs. 1J and K) can be made with an external cathode or without a cathode. In the latter case (Fig. 1K), the liquid in which the counter is immersed acts as the cathode. The thickness and the conductivity of the glass have of course to be chosen in such a way that the resistance of the glass layer does not become prohibitively large. The counter of Fig. 1J does not have electrodes but consists of two concentric glass spheres that are jointed at the top. The space between the spheres is filled with the halogen counting gas. The liquid to be measured is inside as well as outside the counter and acts as anode and cathode. For these applications, the liquid conductivity has to be sufficiently high.

Low-Background Counting

The background counting rate and the detection efficiency are the main factors determining the measuring time for a given sample. The total measuring time, t, that is required to obtain a predetermined root-mean-square error s is given by

$$t = 2\,\frac{-N\omega\epsilon + 2b}{S^2N^2\omega^2\epsilon^2}$$

where N = disintegration rate of the sample; ω = relative solid angle; ϵ = average detection efficiency of the counter, taking into account window absorption; and b = background counting rate. The sample and background measuring times are assumed to be equal, which is the ideal situation for sample counting rates that are lower than the background counting rate. From this it follows that high efficiency, large solid angle and low background counting rate are required to obtain a minimum measuring time. Which of these factors are dominant in a specific case depends on the ratio $N\omega\epsilon/b$.

The most important sources of the background (*24–26*) can be classified as

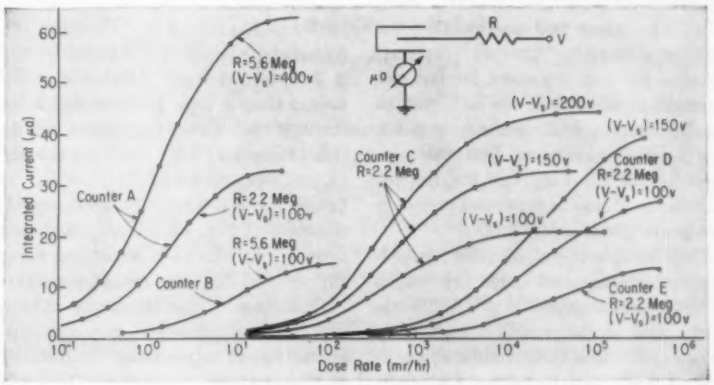


FIG. 13. INTEGRATED CURRENT as function of dose rate for various counter dimensions and operating conditions (Co^{60} source). Dimensions of counters (cm) in order of counter length, cathode diameter and anode diameter: A—40, 4.0, 0.8; B—12, 4.0, 0.8; C—4.0, 1.5, 0.1; D—1.6, 0.5, 0.1; E—1.6, 0.3, 0.1

1. gamma radiation from the environment and from cosmic radiation (60–75%)

2. mesons from cosmic radiation (23–35%)

3. beta radiation from detector materials

4. spurious counter and circuit pulses

5. radiation from the gamma shielding (0.2–0.4%)

The conventional way to reduce background is an anticoincidence arrangement of the beta counter within a ring of guard counters. A novel device for eliminating cosmic-ray mesons consists of a single hollow-anode guard tube (*27*) (Figs. 1I and 12). The beta counter is placed inside the hollow anode so that every meson that strikes the beta counter has to cross the gas volume of the guard counter. This geometry offers a favorable field distribution.

The rare-gas constituent of the filling is a $1:10^{-3}$ neon-argon mixture with a pressure of 200 mm Hg. Bromine, at 0.06 mm Hg, is the quenching agent.

The spherical-anode counter of Fig. 1D can be used with the guard counter. Because of the flattened shape of this beta counter, its gamma sensitivity is considerably lower than that of a conventional end-window counter with the same window opening. For the same reason, the cosmic-radiation sensitivity is also lower (2.9 instead of 5.9 cpm). This facilitates obtaining a sufficiently high guard-counter efficiency; the contribution of cosmic-ray mesons to the residual background will thus be proportionally lower. To obtain a low background, the counter materials have to be selected carefully, e.g., glass and particularly the window material. The only material suitable for thin windows for halogen counters is mica, but its K^{40} content is a drawback. Stainless steel is much better in this respect, but vacuum-tight foils of 1.5–3 mg/cm² are difficult to obtain. Some background measurements are given in Table 2.

The compactness of this guard-counter arrangement keeps the weight of the gamma shield low. A 10-cm-thick lead shield would weigh only 200 kg (*25*). If a 0.5-cpm higher background is not objectionable, the weight can be reduced still more.

In view of the statistical error, a 1.0-cpm background is satisfactory for most low-level counting. An activity corresponding to 0.9 cpm can then be measured with an rms error of 5% in 24 hr. However, for these long measurements, one must rely on the regular behavior of the background. Since testing procedures for low counting rates are time-consuming, it would be more appropriate to reduce the background to a negligible level.

G-M Integrator Tubes

In addition to counting individual discharges, G-M counters can be used to measure integrated current. The latter method offers not only simplicity of circuitry but also the advantage that, in a given range, the current appears to be proportional to the logarithm of the dose rate. A logarithmic behavior of the current over about two decades of the dose rate has been noted (*28, 29*). This phenomenon can be qualitatively explained by two effects: coincidence loss and decrease of the charge per pulse at high counting rate.

Figure 13 shows measurements of a Co^{60} source made with four different counters. The largest counter covers the range 0.5–10 mr/hr, while the smallest one has a range of 1–300 r/hr. The slope of the current curve as well as the maximum current strongly depend on the resistor value R and the overvoltage $(V - V_s)$. For a given counter, the useful range can be somewhat extended to the lower side by a shunt capacitance across the counter. The maximum current, however, is not influenced by this measure, because it is approximately equal to $(V - V_s)/R$. Saturation, however, then occurs at a lower dose rate.

The current output is roughly proportional to $(V - V_s)$. Therefore, the required stability of the power supply is determined by $V/(V - V_s)$. This means that a long plateau and a low starting voltage are important counter characteristics for this application. In practice, values of $V/(V - V_s)$ between 2 and 3 were obtainable for the counters of Fig. 13. Under such conditions, the demands regarding power supply stability are rather moderate.

Operation of the integrator tube at high overvoltage offers the additional advantage of minimizing the influence of temperature variations. Temperature variation causes a shift of the starting voltage and, in turn, a change in current through the counter, if the counter is kept at constant voltage.

From the current characteristics, it can be seen that, for the largest counters, an appreciable current occurs at a dose-rate level as low as 0.1 mr/hr, i.e., 5 μa at 400-volt overvoltage and $R = 5.6$ megohm. Under these conditions, the current due to cosmic and environmental background radiation amounts to about 0.8 μa. This large current yield makes this counter very suitable for area monitoring or for operating alarm devices. Also, the circuits can be simple, cheap and reliable. The smaller counters, C and D of Fig. 13, are suitable for the higher 0.1–10 and 1–300 r/hr, respectively, required for portable monitors.

The logarithmic range of this type of instrument can be easily extended by putting two or more counters of different size in parallel, each of course with a separate series resistor.

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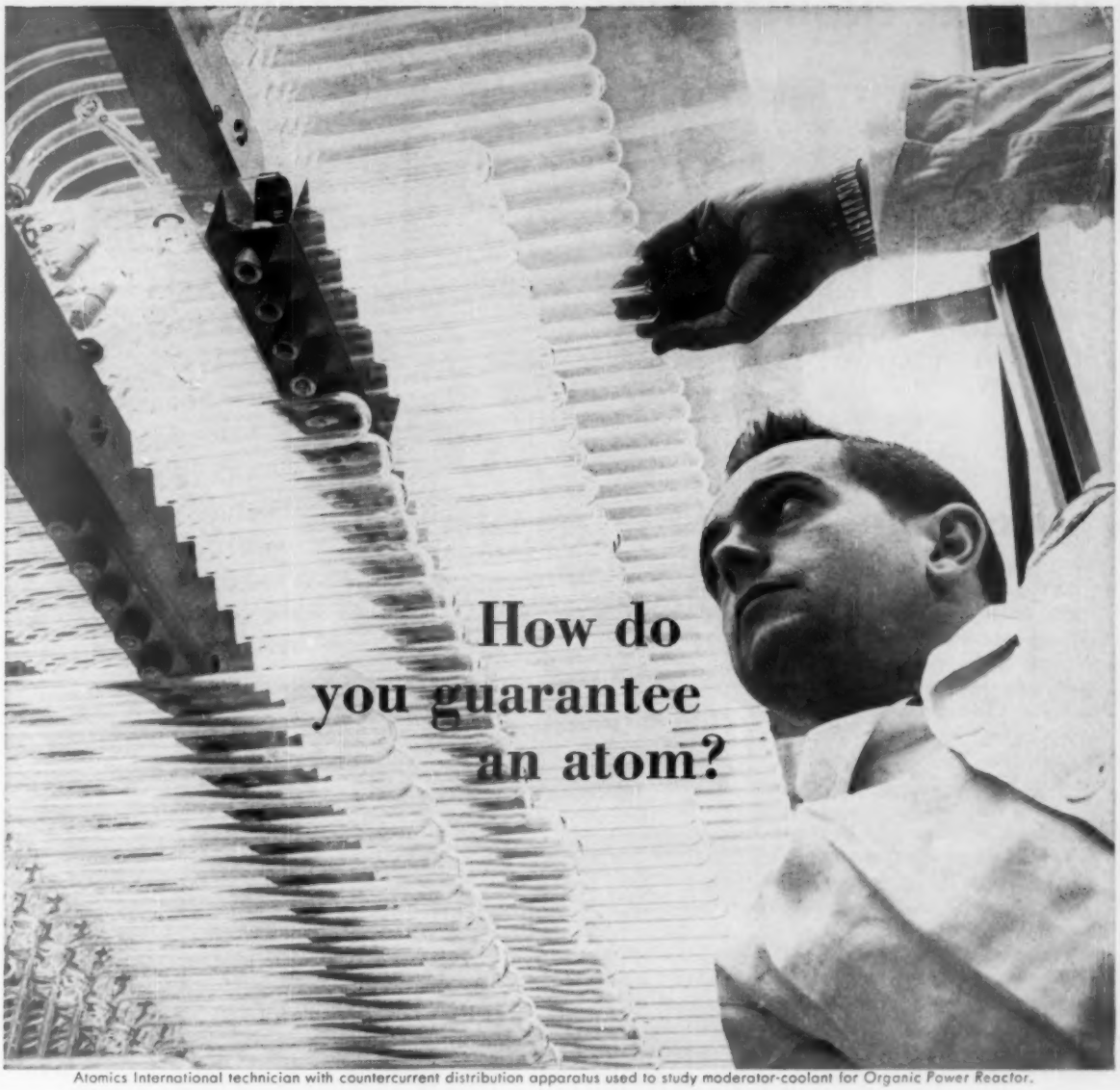

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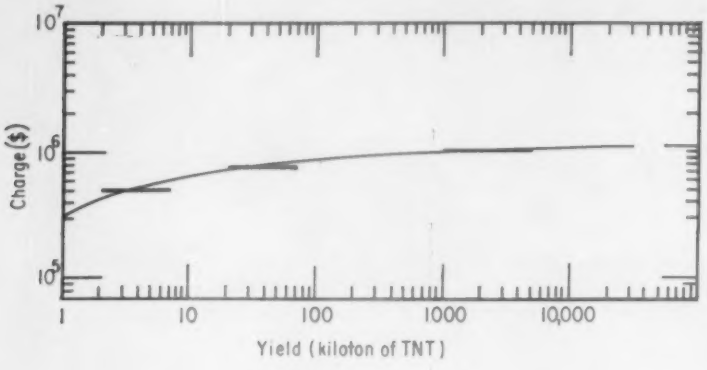

FUSION-DEVICE PRICE curve drawn through price quotes (horizontal bars) released by AEC shows little variation with energy yield. Service charges account for about half of price. Since many of these are one-time charges (such as site survey), repeated detonation at same site would be cheaper

Plowshare Projects Reviewed at Cleveland

As the difficulties of developing controlled fusion continue to be stubborn, the idea of getting at the huge resources of fusion energy via controlled nuclear explosions (Project Plowshare) seems more and more worthwhile. Speakers at a conference on Plowshare held during the 5th Nuclear Congress (this April in Cleveland) repeatedly made the point that we can today through nuclear explosions generate large quantities of fusion energy at low unit costs. The AEC price list for nuclear devices (see figure) shows that above 100 kilotons the price levels off at about $1 million regardless of size. Thus a 1-megaton yield at $1 million figures out to an energy cost of 25¢/10^6 Btu or less than 1 mill/kwh(th). The 10-megaton size provides energy at less than 0.1 mill/kwh(th)!

The problem, of course, is to find practical schemes for using energy released in this way. At the Cleveland conference (sponsored by the National Industrial Conference Board), John S. Kelly, Director, Project Plowshare, Division of Military Application, reviewed the schemes being considered. Although his office has received over a hundred suggestions for plowshare applications (including climate control and diamond production), Kelly reported that the current program is concentrating on four possible uses: excavation, isotope production, oil recovery and electric-power production.

These projects can draw on the data from five underground test shots held to date: the Rainier test in September, 1957; and the Logan, Tamalpais, Neptune and Blanca shots in October, 1958. Further Plowshare detonations will have to await possible international agreements on peaceful nuclear explosions. In the meantime, however, thinking and preparations are going ahead. Project Chariot is looking into the details of using a nuclear device to excavate a harbor in Northwest Alaska, between Cape Seppings and Cape Thompson, north of the Arctic Circle. (The harbor would give access to nearby mineral resources.) Project Gnome plans to set off a 10 kiloton underground shot in the salt beds near Carlsbad, New Mexico to investigate the production and recovery of radioisotopes in large quantities. Salt formations appear convenient as a material that will retain isotopes produced during the denotation and still allow recovery; it may also eventually prove useful in confining the thermal energy released to provide a heat source for a power plant located above ground. In this scheme, a coolant pumped down through the molten salt would remove the heat to a steam generator.

Power Production

An alternative scheme for generating electric power from nuclear explosions was proposed at the Cleveland conference by Clarence Zener (Westinghouse). He would excavate two large underground caverns and connect them with a tunnel containing a turbogenerator. An explosion would be set off in one cavern, heating the gas that fills the cavern and driving it through the turbine to the other cavern. The next explosion is set off in the second cavern, driving the gas back through the turbine again to the first cavern. In this way the plant could turn out a steady power supply from an alternating series of explosions. Heat exchangers on the low pressure side of the turbine would remove waste heat to keep the average temperature at a steady-state level.

The main technical problem with his scheme, Zener claims, is whether caverns can be built that would hold up for a long enough time under the repeated explosions. Beyond this there is the economic problem; roughly speaking the capital costs and fuel costs could be made as low as one wants by going to larger caverns and bigger, more frequent explosions. The question is whether the plant size needed to get competitively-priced power would be too large to be useful. Zener estimated the cost for the excavation of two 600-ft-diameter underground spheres at $20 million (@ $5/yd^3). He further estimated that a 1-megaton explosion once a week in this system would provide power at a cost of the order of magnitude of current rates; but, by today's standards, the plant output would be large—about 7,500 Mw(th).

Shale-Oil Recovery

A Plowshare project to use underground explosions to produce oil from oil shale has evolved to the point where the AEC and the Bureau of Mines have invited the oil industry to share the expenses for a 10-kiloton test shot in the Green River oil shale in Colorado. C. C. Anderson (Bureau of Mines) reported in Cleveland that over half of

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the oil companies had already replied to the invitation. He also quoted the results of a detailed cost study of a full-size oil-shale project; the cost of shale oil produced in this way comes to $2.35–2.90 per barrel versus $2.25 charged today for similar-grade oil.

Oil shale in the U. S. alone contains an estimated 700 billion barrels of oil which is at least double the world's known crude oil reserves and 15 times as large as the U. S. reserves. Previous to Plowshare, oil companies were already experimenting with ways to mine oil shale and retort it in special plants. With the Plowshare scheme, the explosion would break up a large volume of underground shale that would be left in place. Heat from the nuclear device would drive some oil out of the shale, but most of the oil would be retorted by burning some of the oil *in situ* with oxygen piped in through wells. Other wells would pump the unburned oil to the surface. In this method the cost of mining the shale (which came to 50% of the total cost in the conventional proposals) is replaced by the cost of the nuclear device which would be much less—only ~12¢/barrel of oil. Although the Plowshare method requires wells to supply oxygen and remove the oil, the cost of these is offset in the conventional schemes by the costs for shale handling and disposal and the retort.

Salt-Water Conversion

The results of Project Gnome may encourage a plan described in Cleveland by Roger E. Batzel of Livermore for distilling fresh water from sea water. The heat from a nuclear explosion would be stored in a salt-formation cavity about a mile below ground. A pipe would carry salt water down to the cavity where it would change to steam and exit to the surface as fresh water. The entrance and exit pipes would form a crude regenerative heat exchanger so that the fresh water on the way up heats the salt water on the way down. With the pressure available a mile below ground, the temperatures in the heat exchanger and cavity might be adjusted to operate the cavity at above the critical point of water. Under this arrangement no energy would be lost in supplying heat of vaporization and the cost of distilling sea water might be reduced to as low as $40/acre-foot.

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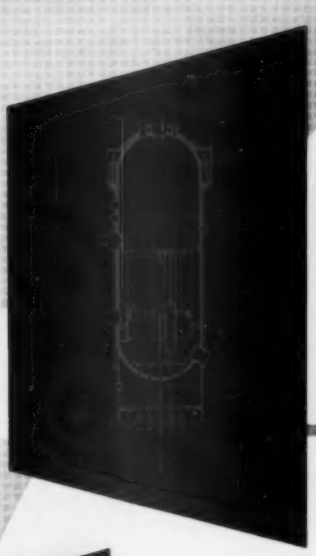

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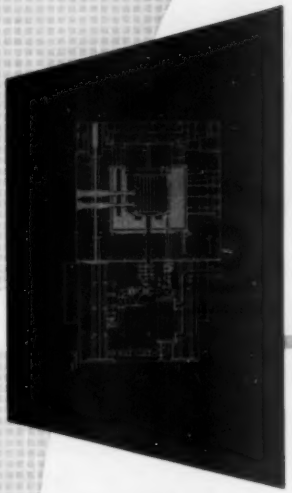

5 MW$_{th}$

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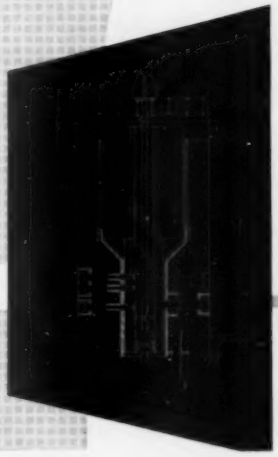

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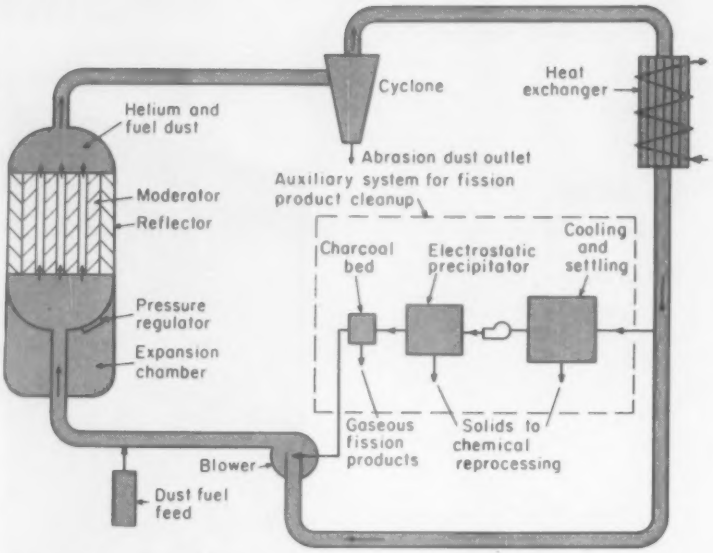

DUST-FUELED REACTOR flow diagram. Each cycle, small fraction of He-fuel dust suspension passes through fission-product removal system

Armour Dust-Fueled Reactor

By D. KRUCOFF

Armour Research Foundation, Chicago, Illinois

The Armour Dust-Fueled Reactor (ADFR) uses a new fuel form—fissionable dust carried in a gas—that promises the advantages of 2,000–3,000° F operating temperatures and a low-cost fuel cycle.

Since the ADFR concept was first described in 1958 (*1*), a development program (*2, 3*) has been sponsored by the AEC to experiment with the proposed fuel and make analytic studies.

Reactor Concept

The ADFR fuel is an aerosol-type suspension that has almost the same uniformity and handling ease as a gas. The core can be simply a block of ceramic moderator (such as graphite or beryllium oxide) with through holes for passage of the fuel-laden gas. If graphite is used as the moderator, the chemically compatible fuel dust would be uranium carbide; the ducts and chambers in contact with the fuel could be lined with silicon carbide and the gas would be helium. If beryllium oxide is used as the moderator, the fuel dust would be uranium dioxide, the lining material could be aluminum oxide, and the gas carbon dioxide. We call these systems respectively the carbide and the oxide systems.

The figure shows a flow diagram of the ADFR system. All ducts are lined with ceramic thermal insulation and covered with a gas-tight metal skin. High-temperature fluid leaves the core and plenum chamber and enters a cyclone separator that removes all particles substantially larger than the fuel particles. (For instance, pieces might break off from the ceramic lining.) The fluid next enters a heat exchanger or boiler where it generates steam. The heat exchanger could be a conventional metallic boiler with the

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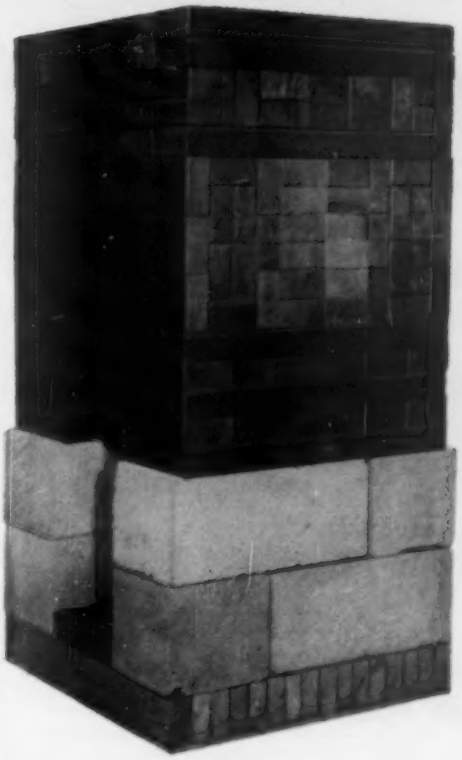

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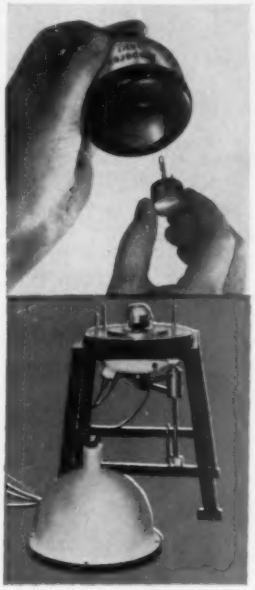

In recent years, the measurement of low level radiation has become increasingly important, particularly in connection with the radioactive contamination of the atmosphere, water supplies, foodstuffs, and the waste material from medical, radio-chemical and nuclear laboratories. Hence, an acute need has developed for a reliable, ultra-sensitive Geiger counting system which combines accuracy and compactness at a moderate cost.

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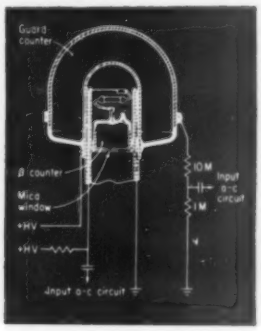

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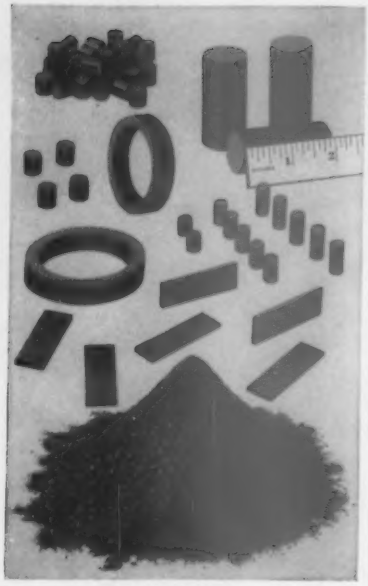

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REACTOR ROUNDTABLE

This article starts on page 100

2,000–3,000° F reactor fluid taking the place of the combustion gas (that typically has temperatures in the same range). Higher-temperature process heat would require a ceramic heat exchanger.

On leaving the heat exchanger, most of the fluid enters a blower and recirculates; a small part of the flow passes through a fission-product removal system.

An expansion chamber, connected to the lower plenum chamber through a pressure regulator, damps power fluctuations. During a power transient the pressure regulator lets fuel into the expansion chamber and so terminates the transient. The fuel then returns slowly to the system through an orifice.

We have also considered an internally cooled ADFR core with a nonradioactive primary loop (which would ease maintenance and reduce fuel inventory). The core resembles a shell-and-tube heat exchanger with fuel-laden gas on one side and pure gas on the other. The fuel circulates at low velocity through the core and the fission-product cleanup system. The pure coolant gas circulates at high velocity through the core and the primary loop. The core tubes are made of moderator material to get high neutron economy. Some leakage of gas through these tubes into the fuel region can be tolerated since it will be removed in the fission-product cleanup system. The power density is more limited than in the externally cooled case first discussed but compares very favorably with other gas-cooled reactors because of the high operating temperatures.

Thermodynamics

Because the energy release occurs in fine particles in the coolant stream, relatively little (perhaps 15%) of the energy reaches the channel walls. Also, heat transfer from the channel walls back to the fluid is excellent due to the high temperatures and radiation absorption of the particles. Thus the channel-wall temperatures are expected to be only 50–100° F above the bulk-fluid temperature. The power density in the core is given by simple heat-transport calculations. For instance, the reference-design core (with helium as the carrier gas) has a pressure of 30 atm and inlet and outlet temperatures of 1,000° F and 2,500° F respectively. Hence an average gas velocity of 220 ft/sec will remove 500 Mw of heat. Even higher gas velocities, and corresponding power levels, are believed practical.

The large temperature rise through the core of the ADFR will cause a large axial variation in the fuel-dust concentration. However, multiregion calcu-

Major Uncertainties . . .

Fuel Properties. Although in experiments to date, particles of the correct size circulate well with very little erosion, wall deposit and erosion need further investigation, particularly in components such as the compressor and heat exchanger. Also, no in-pile or high-temperature work has yet been done.

Control. Reactor-stability studies will require more detailed data on the uniformity of the fuel suspension during circulation. High-speed fluctuations of the concentration are particularly important.

Compressor. A specially designed compressor will be needed to minimize the problems of rotor erosion and dust accumulation in the compressor.

Leaktightness. In the present design a secondary He loop may be required to isolate the primary He loop from the steam side.

Eventually a direct gas-turbine cycle might eliminate the heat-exchanger leaktightness problem; then only the compressor precoolers, which operate at relatively low temperatures, would be a problem. (This appears quite attractive for an internally cooled ADFR with a primary coolant of pure helium.)

. . . Major Advantages

High Temperatures. Temperatures of 2,000–3,000° F allow good thermal efficiency and high power density in power reactors; also reactor heat at these temperatures could support a wide range of endothermic chemical processes.

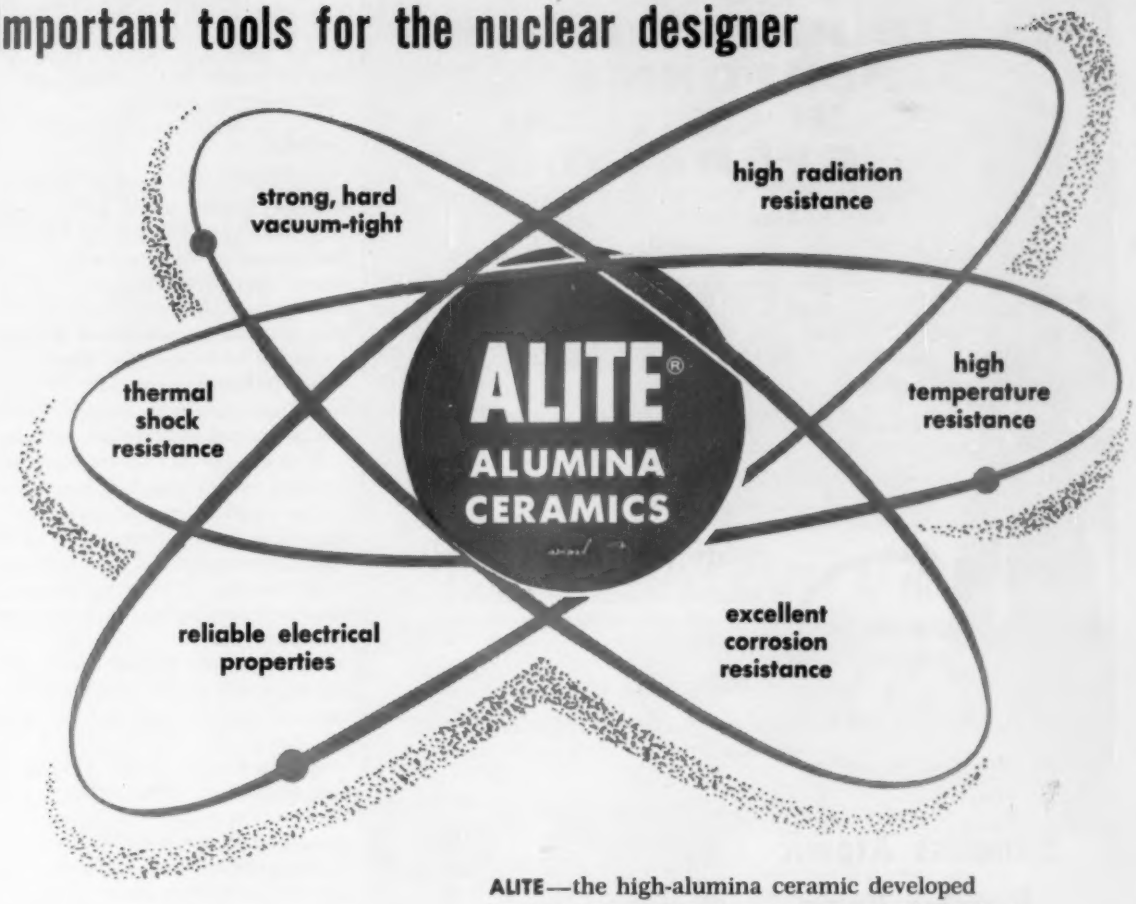
Reduced Corrosion. If helium is used, corrosion is limited to impurities in the helium, fission products, and the fuel dust (together, these have a volume only 0.1% that of the He).

Low-Cost Reprocessing. To reprocess the fuel, the solid particles (fuel and solid fission fragments) are simply removed from the carrier gas and put through the reprocessing plant; no cladding or matrix material is involved.

High Neutron Economy. The reactor core is virtually free of neutron poisons—there are no control rods, fuel-element matrix and cladding materials or structural material and the fission-product concentration is low. Breeding therefore seems assured with the Th-U^{233} cycle.

Fluid-Fuel Advantages. In common with other fluid-fuel systems the ADFR has: (a) no fuel-element fabrication costs, (b) unlimited burnup, (c) no control rods, and (d) continuous operation.

Important tools for the nuclear designer



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lations show that the effects of fuel non-uniformity in the ADFR are of small consequence.

Safety

The ADFR is believed to be unusually safe, because of the large prompt temperature coefficient of the fluid fuel and because no chemical reactants and liquids are present that will rapidly form gases. Of course, one accident that can cause a transient would be the accidental addition of fuel dust to the core. Rather than use control rods to control such transients, we have studied the capabilities of a pressure regulator.

With an ideal pressure regulator, the pressure will not change during the disturbance and only the temperature will rise. This rise depends on the temperature coefficient and the excess reactivity inserted. The prompt temperature coefficient of the fuel has been calculated to be -1.63×10^{-4} C^{-1} arising from fuel-density changes with the expansion of the carrier gas with temperature. We find that, for an extreme case of a 20% addition to the critical loading, we obtain a 4.7% excess reactivity. This combined with the above temperature coefficient gives a temperature rise of 542° F—not at all large compared with the anticipated operating temperatures.

So far we have discussed only an ideal pressure regulator. To bracket the behavior of a practical pressure regulator we next assume no pressure regulator at all and further that the core and plenum chambers form a sealed system. We use a simplified model of the gas dynamics which assumes that an interface is maintained between the fluid expanding from the core and the fluid in the plenum chambers during the short time required to reach peak power. Thus, expansion of the excess fuel out of the core is resisted by the fluid compressed in the plena. Also, we conservatively assume that the fluid originally in the core continues to be heated throughout the transient. The volume of the plenum chambers together was taken equal to the core volume. With excess fuel added instantaneously, the peak power is reached when the excess fuel is removed from the core in the fluid expansion. Again for a 20% fuel addition (in a reference-design reactor operating initially at 500 Mw), the pressure and temperature increases are 13.5 atm and 1,800° F from initial

Reference Design

Core (right cylinder, radial reflector)	
Height	10 ft
Diameter	6 ft
Reflector thickness	2 ft
Fuel (93% enriched U^{235} as UC_2)	
Critical mass	17.4 kgm U^{235}
Fuel/channel volume ratio	0.0507%
Fuel/moderator atom ratio	146.7 ppm
Coolant gas (helium)	
Fractional free-flow area	45%
Moderator and reflector (graphite)	
Density	1.476 gm/cm³
Core temperature	2,000° F*

* Uniform through core and reflector.

values of 30 atm and 2,000° F, with the power peak reached in 14.5 msec. These values can probably be tolerated and would be decreased not only by the pressure regulator but also by expansion into the external system.

Fuel Dust Experiments

We have carried out experimental studies on circulating gas-dust suspensions in a square 5- × 5-ft loop formed of 2-in.-diam glass tubing. Gas velocities of about 100 ft/sec, depending somewhat on dust concentration, have been achieved with a ¾-hp blower; a 3-hp blower has given a gas velocity of 147 ft/sec. To start with, we used aluminum-oxide particles (900 mesh or about 10 microns average size) to simulate UO_2 and atmospheric-pressure air to simulate helium at about 7 atm pressure (the ADFR system pressure would be at least 10 atm).

The powder dispersed readily upon introduction into the air stream and circulated well in the loop with very little deposit or erosion either in the blower or on the tube walls. Stopping the blower results in almost all the dust gradually accumulating in the blower as it comes to rest. Upon restarting the blower the concentration of circulating dust gradually builds up to a constant value after about a 10 minute period. We were able to circulate dust concentrations up to 0.2% by volume without difficulties; this corresponds to about four times the UO_2 concentration needed for criticality.

In addition to the aluminum oxide experiments, we have also done some work with UO_2. Nitrogen was chosen as the carrier gas rather than air to prevent oxidation to higher oxides. We first introduced 10 gm of very fine

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This article starts on page 100

powder (about 1 micron average size). As expected, very soon after entering the gas stream the particles plated out rather uniformly over the glass walls of the loop. Next we tried larger size UO_2 particles (average size 8 microns) and found they circulated as well and behaved in general like the previously used 10-micron aluminum oxide. In fact, after a few minutes the 8-micron material cleaned the 1-micron particles from the straight sections of the loop. Up to 40 grams of 8 micron UO_2 powder have been added to the loop. The concentration of circulating dust reaches an equilibrium, as with the aluminum oxide powder, and remains constant.

Reactor Physics

Two-group calculations were made to determine the fuel concentration for the reference design shown in the table. Because of the large migration area of this reactor type, the thermal-neutron radial flux varies only 18% from the center to the edge of the core. This uniformity, together with the high thermal flux that is a consequence of the light fuel loading and high power density, make the ADFR attractive as a test reactor. For instance if the reference design operates at 500 Mw, the average thermal flux in the core is 1.6×10^{15} n/cm² sec.

The physics calculations show that substantial reductions in fuel concentration can be had by increasing any of the reactor dimensions. The use of U^{233} as fuel also reduces the fuel concentration; the reference design, which is not optimized for U^{233}, would have a critical mass of 12.8 kgm and a U^{233} fuel concentration of 0.035% by volume. The high neutron economy of the ADFR suggests that breeding on the U^{233}-thorium cycle is quite possible.

* * *

This article is based on the work of a number of people at Armour Research Foundation. The author wishes to express his appreciation to all of them, in particular the following individuals who contributed in the indicated fields: T. M. Rymarz, fuel dust experiments; F. Narin, reactor physics; D. Langford, thermodynamics; W. E. Loewe, safety. This work was performed under U. S. Atomic Energy Commission Contract No. AT(11-1)-603.

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3. ARF Quarterly Progress Report No. 2 USAEC contract AT(11-1)-603

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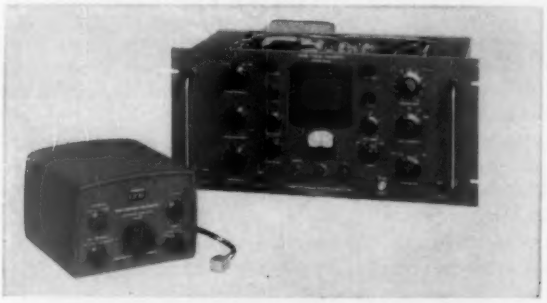

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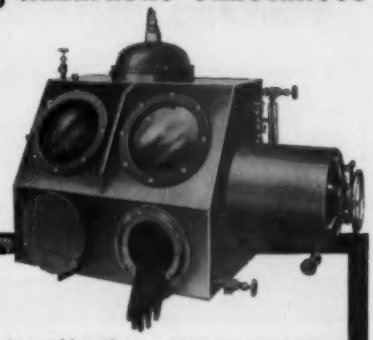

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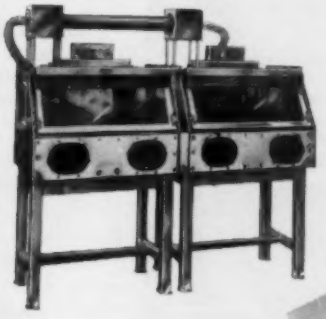

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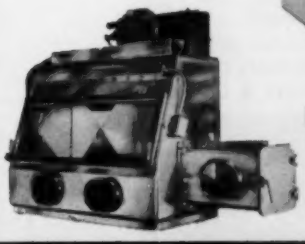

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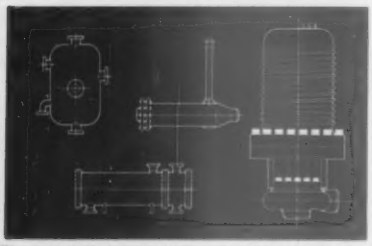

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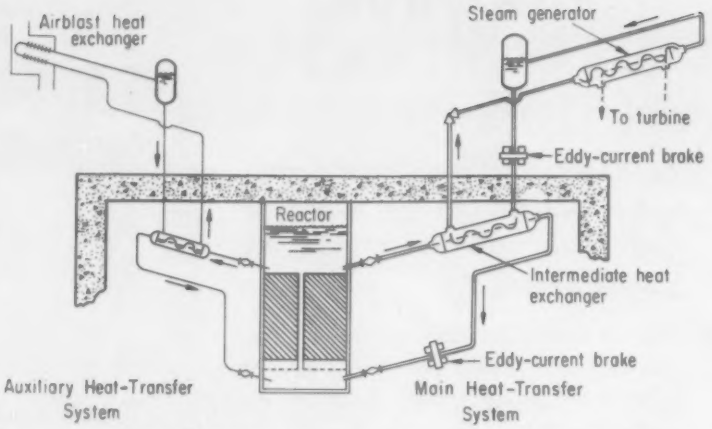

FIG. 1. SRE COOLANT SYSTEMS. Convection-head magnitudes (~0.3 psi in primary loop and 0.7 psi in secondary at full-temperature gradient of 460° F) were calculated to be sufficient to maintain flow rates of 10–15% of full flow after simultaneous shutdown of reactor and pumps

SRE Decay-Heat Problem Solved by Eddy-Current Brake

By W. S. DE BEAR
Atomics International Div., North American Aviation, Inc.
Canoga Park, Calif.

The early operation of Sodium Reactor Experiment (SRE) verified a predicted need for a sodium-flow throttling device to prevent excessive thermal stresses in the reactor core and sodium piping after a shutdown or scram. When the reactor is shut down circulation of sodium through the reactor is by thermal convection. The result is that sodium, at a relatively low temperature, is brought into contact with piping that is still at a high temperature, thereby leading to excessive thermal stresses. These stresses have been minimized by installing two eddy-current brakes to control the sodium flow in proportion to the heat generation, resulting in constant temperature gradients.

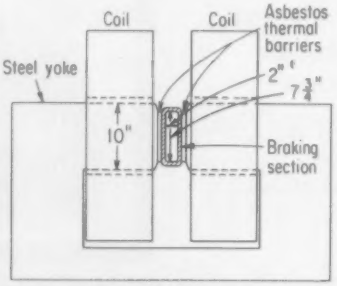

FIG. 2. EDDY-CURRENT BRAKE and throat section. Induced eddy currents generated in flowing liquid metal oppose flow and thereby provide necessary throttling effect

One brake is in the primary system (Fig. 1), the other is in the secondary system. Each is constructed as shown in Fig. 2. Braking action is provided by a direct-current electromagnet, which creates a strong magnetic field across a modified section of 6-in., schedule-40, type 304 SS pipe. Eddy currents generated in the sodium by its motion through the magnetic field exert a retarding force on the flowing sodium. With a power of 2,400 watts supplied to the magnet, flow after scram is reduced from 1,200 to 12 gpm against a convection head of 3 psi.

Need Predicted

Several design-stage analog studies of the post-scram transient behavior of SRE concluded with the prediction that some control of convective flow after shutdown would be desirable to eliminate the possibility of rapid temperature changes in various reactor

components. However, owing to several uncertainties in the early analytical work (e.g., pressure drops across the reactor core and other components) and the extent of thermal coupling between coolant and graphite, it was decided to obtain further experimental verification of the need for such flow-regulating equipment. Accordingly, a series of planned scrams were conducted at low power and with small temperature gradients across the reactor core. Calculations based on extrapolations to full power from the data thus obtained confirmed the predicted requirement for convection-flow control (*1*).

Figure 3 illustrates the results of this work. The calculated temperature decay at the exit from the reactor core, obtained from the extrapolated data, is compared with the actual temperature decay (Curve *A*), which was experimentally determined at a later date. Curve *B* demonstrates the considerable improvement that has been realized by the convection-flow control equipment.

As soon as the value of flow-control capability had been definitely established, an evaluation program of possible methods for implementing the desired throttling effect was started.

Selection of Equipment

Preliminary consideration of methods for restricting coolant flow after scram was directed toward valves, with initial emphasis on existing equipment in each of the main heat-transfer loops. The main primary-coolant valves proved to be a partial obstacle to this solution because plug valves had been installed to minimize the primary-loop pressure drop and they were not suitable for precise throttling nor readily adaptable to automatic actuation.

A number of alternative systems were proposed in which one of the main valves, acting in its proper capacity as a blocking valve, was used in conjunction with a by-pass line and a separate throttling valve. The added complexity contributed by the duplication of equipment and the necessity for controlling two valves, however, were felt

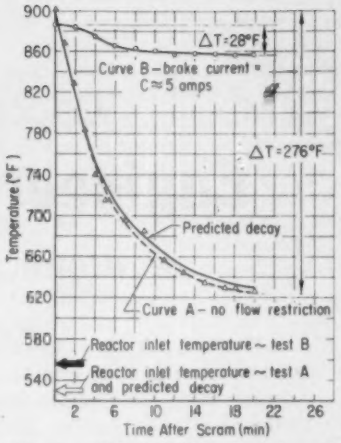

FIG. 3. TEST RESULTS. Fuel-channel exit temperature, with restricted flow, is compared with similar test during which full convective-flow rates were permitted to develop in main heat-transfer loops

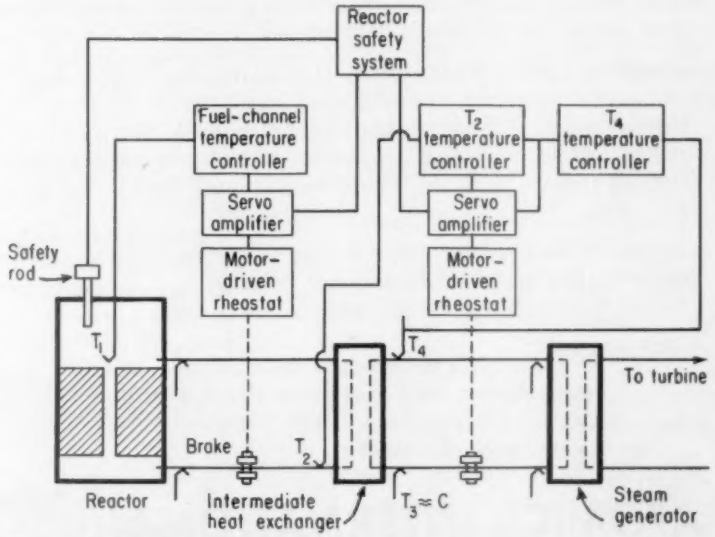

FIG. 4. CONTROL SYSTEM. With this convection-flow-control system, it has been possible to hold temperature drop of coolant leaving fuel channel to $<20°$ F during first hour after scram while maintaining reactor inlet temperature essentially constant

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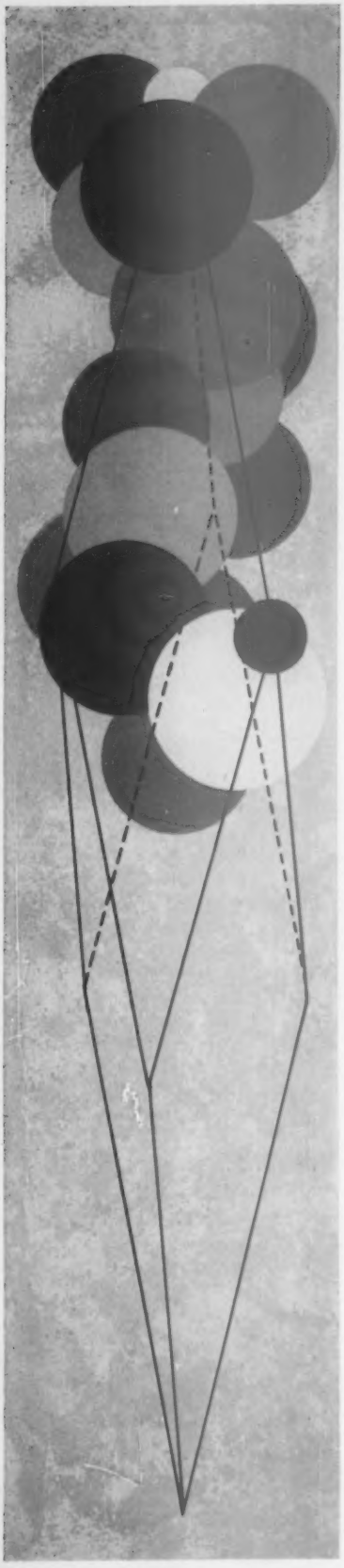

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to be too disadvantageous for this use.

The replacement of one of the existing valves with a suitable throttling valve and automatic actuator was weighed against the increased pressure loss that would be incurred. Also of some concern were the elevated temperature and radiation levels to which the valve actuators would be subjected during reactor operation.

The addition of an auxiliary electromagnetic pump to oppose flow in each of the main loops represented still another approach for achieving the required control. In this instance the relatively large power drain of such equipment (of significance after a loss of normal electrical power when emergency power would have to be used) was an undesirable disadvantage.

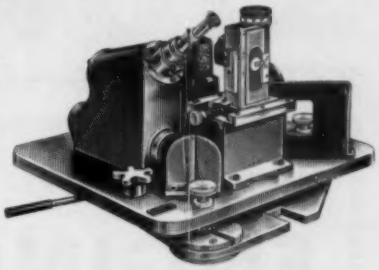
The recommendation for application of the eddy-current brakes resulted from a comparison of their simplicity, low pressure loss, low power consumption and ease of control against similar considerations relating to the other potential solutions. Ease of fabrication and rapid procurement were other important factors resulting in their selection as was the knowledge that they could not, by malfunction, cause a complete stoppage of coolant to the reactor core, nor could they fail in a "shut" position and thereby hamper the reactor restart operation. Finally, they could be directly coupled to the battery bank that supplies vital and emergency power to the reactor plant.

Design and Fabrication

The equations governing behavior of the eddy-current brake were derived by R. S. Baker (*2*) based on work by R. Rudenberg (*3*) on the eddy-current drag produced in spinning copper disks. The brake consists of two large d-c magnet coils mounted on a mild steel core and situated so as to pass their magnetic flux through a flattened section of the main 6-in. sodium piping.

Flow control is obtained quickly (time constant: 3.7 sec) by varying the coil currents and, therefore, the flux density. The equipment has no moving parts to adversely affect its reliability or require inspection or maintenance. It is insensitive to local temperature and radiation levels, requires no penetration of the main piping or liquid-metal seals and causes a very low pressure drop under normal flow conditions. This last advantage was later found to

OPTICAL STRAIN-MEASURING INSTRUMENT



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be <1.5 psi at a flow rate of 1,200 gpm.

In consideration of the many apparent advantages of the eddy-current brake, the fabrication and testing of two units was initiated. Although no previous operating experience was available, there was little doubt as to the success of the undertaking because the operating characteristics were amenable to theoretical analysis from first principles. Test results were considered so satisfactory that installation of a brake in each of the main loops was immediately initiated.

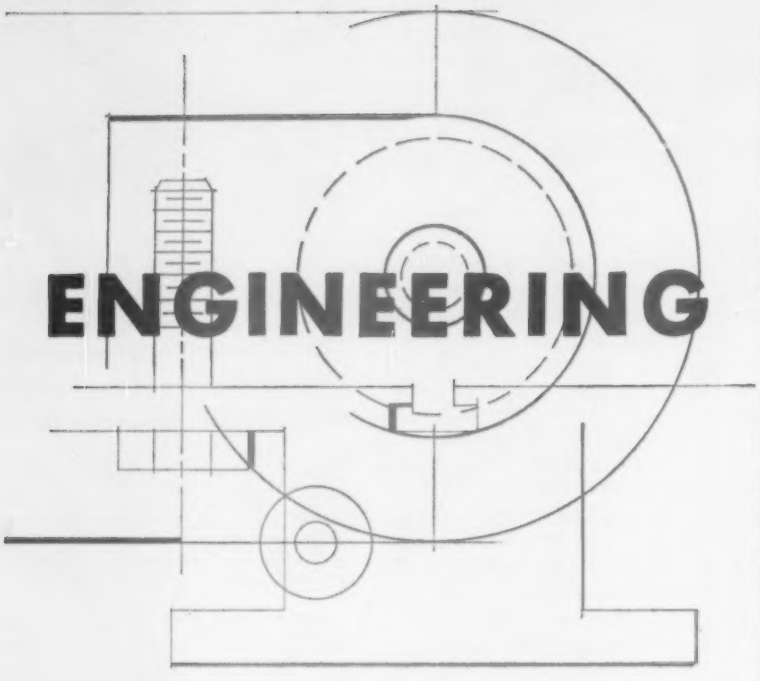
In the SRE installation, the brake coils are connected in parallel across the 120-v battery bank that supplies emergency power to vital equipment when normal power is lost. This arrangement was feasible because of the small power drain under normal operating conditions. Although the original design was based on a combined coil current of 20 amp, and testing was carried out to 25 amp, normal operational requirements are only 5–10 amp per brake for a maximum total power consumption of 2,400 watts.

Control System

The method of control chosen to fulfill the specification for constant system temperatures is illustrated schematically in Fig. 4. Operation of the primary eddy-current brake is governed by a temperature measurement at the fuel channel exit. The temperature controller set-point automatically tracks the fuel channel temperature during normal operation, becoming fixed at the instant of scram. Deviation of the actual temperature from set-point temperature is then used for regulation of brake-coil currents.

The fixed set-point approach was later modified by the addition of an automatic programmer to permit a temperature drop at an allowable rate of 50° F/hr. This change was made to avoid excessive restriction of primary-coolant flow.

Control of secondary-coolant flow is obtained, in like manner, by deviation of actual temperature from the set-point temperature T_4. To ensure a satisfactory reactor inlet temperature, however, an override control is assigned to a controller monitoring the primary-coolant cold-leg temperature T_2. This instrument remains inactive unless temperature T_2 deviates beyond the permissible excursion limits of 20° F. It



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then assumes full control until the temperature has been returned to an acceptable condition.

A series of reactor-scram tests was undertaken to obtain data for the final evaluation of the new equipment and its control system. This work provided the necessary verification of control capability by demonstrating that reactor temperatures could be maintained near pre-scram levels for intervals of 2–3 hr or longer if necessary.

The ability to maintain constant reactor temperatures after scram has proven to be of considerable value during the reactor restart procedure by both simplifying and accelerating this operation. With the main loop flow control, the reactor can be returned to power as rapidly as the safety circuits will permit. On numerous occasions, after test scrams or others where the cause of scram could be readily determined and corrected, the reactor has been returned to significant power levels within 30 min after scram.

Also, as a consequence of the excellent throttling characteristics of the eddy-current brakes, it is no longer necessary to stop the main pumps after a reactor scram. Present practice is to drop pump speeds to minimum values (~100 rpm) and to compensate for any excess flow by slight current increases to the brake coils. This procedure has eliminated the flow surge previously associated with the pump restart.

The automatic control also eliminates the necessity for continuous, manual adjustment of flow with increasing power level. During this operation the fuel channel exit temperature tends to increase, causing an automatic relaxation of the braking current to provide the desired matching of power level and coolant flow.

It should be emphasized, however, that eddy-current brakes are not considered a panacea for every liquid-metal throttling problem, and their choice does not reflect any lack of confidence in other types of equipment. However, on the basis of their excellent performance in the present SRE application, they are heartily recommended as throttling devices for unusual flow-control situations.

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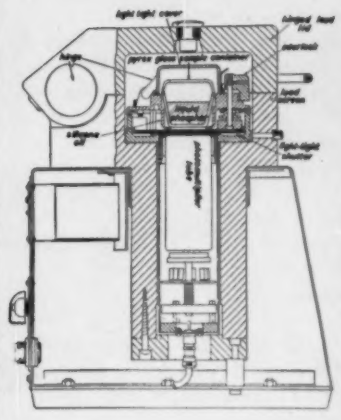

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Arthur D. Little Report Finds . . .

Radiation Use Is Small— but It Does Have a Future

Industry can be expected to adopt one or two new radiation processes a year for the next few years. But radiation is not now a major processing tool and cannot be expected to become one for at least five years. These are among sobering conclusions of a report by Michael Michaelis and S. Edward Eaton of Arthur D. Little Inc. The authors presented a summary of the study at the recent Cleveland Nuclear Congress.

The study had two sponsors. One was the CEM group—an association of General Aniline and Film, Emerson Radio and Phonograph, and Revere Copper and Brass working in the radiation-development program of the AEC's Office of Isotopes Development. The other sponsor was GE's Hanford Atomic Products Operation under contract to AEC's Division of Production.

In NUCLEONICS' view the report offers grounds for both optimism and pessimism as to the future of process radiation. One can infer that radiation has been oversold in the past, but the report suggests that a more basic and scientific approach to its possibilities may recover lost ground and conquer new areas. If prospects for drastically cheaper radiation become reality, one or more large scale uses will be seriously reconsidered for their commercial possibilities.

Present Status

Two radiation processes are actually in commercial use now. These are Ethicon's sterilization of sutures and irradiation of polyethylene to crosslink such things as wire insulation. Meanwhile a few commercial processes have been introduced and then dropped as uneconomical. In some instances the products have been replaced by non-irradiated products. Among irradiated products that have disappeared are radiation-sterilized eye ointments and crosslinked polyethylene bottles and pen cartridges. The bottles and cartridges have gone to linear polyethylene, produced by conventional chemistry.

Meanwhile there are about 10 processes in various advanced development stages. Information about some of them is hard to get; companies value their development secrets too highly to talk openly. One product that has advanced beyond company secrecy is a semipermeable membrane for electrodialysis of water. American Machine and Foundry makes it by radiation grafting of styrene to polyethylene. Further from the market but probably moving toward it are other processes that are in research rather than development.

Pessimism and Optimism

Radiation has not been the panacea that many hoped it would be. Because it is nonspecific in most of its actions studied so far, it has been hard to find things it will do better than other means. Chemistry and heat produce free radicals, for example.

On the other hand there are grounds for optimism. Few companies that have set out on serious radiation-research programs have abandoned them. Industry is currently believed to be investing $10-million each year in these programs. Faith in technology leads one to anticipate that the spenders can expect a return.

Potential Value

Several things can happen in the future to push radiation farther into

Can OMR's Make C^{14} Compounds Cheaply?

Quinoline in the coolant-moderator channels of an organic-moderated reactor might produce valuable amounts of C^{14} and C^{14}-labeled compounds, suggests Richard Stephenson, professor of nuclear engineering at the University of Connecticut. His rough calculations show that one might get large amounts of low-specific-activity C^{14}-labeled compounds at practically no increase in operating cost. Purity would not be good enough for biological purposes, but the products would be suitable for chemical uses. Moreover a gradual shift from quinoline to terphenyl as moderator would add reactivity to compensate for fuel burnup.

The reaction that produces C^{14} is $N^{14}(n,p)C^{14}$ with a 1.75-barn thermal cross section. C^{14} recoils with ~40 kev and labels molecules of its parent compound and degradation products. All you have to do is get N^{14} into the moderator.

Quinoline (C_9H_7N) appears to be the most suitable nitrogenous material for mixing with the terphenyl moderator. Its boiling point is probably high enough at 237.7° C. Hydrogen-to-carbon ratio is the same and radiation stability is about the same for the two compounds.

OMRE is pressurized to 300 psi, which would raise the boiling point to usable values. Moreover it would probably be better to use quinoline residues than pure quinoline. These are nitrogeneous bases left after distillation of pure quinoline. They have higher boiling points and are available at reasonably low prices.

Stephenson has made preliminary computations for quinoline in the 45.5-Mw(th) reactor being designed for Piqua, Ohio, by Atomics International. Fuel enrichment is 1.8% and fuel-to-moderator volume ratio is 0.307. Changing from terphenyl to quinoline would reduce new-core multiplication from 1.106 to 1.041. C^{14} would be produced at the rate of 1 atom for 10 fissions. If you operate at 80% load factor and half the time with quinoline you will produce 190 curies of C^{14} a year with a specific activity of 3 μc/gm. This is to be measured against ~10 curies per year sold from Oak Ridge at the present price of $22,000 per curie—or several times this if you buy your C^{14} in compounds.

the area of commercial usefulness. More basic knowledge (for example, of radiation-reaction mechanisms) and lower radiation costs are among factors that would be beneficial.

Basic knowledge. So far the philosophy of many researchers has been to irradiate and see what happens. The conclusion frequently is that radiation doesn't do anything that can't be done better and cheaper otherwise. But Michaelis and Eaton note that more precisely directed research is likely to produce more interesting results in the future. For example, radiation produces other excited species besides free radicals; means for obtaining useful effects from them might be discovered. There may well be chemical or physical additives that will work with radiation to produce more interesting results than radiation alone. Much could come from a study of the effects of process parameters like temperature and pressure.

Hopefully one can look for higher *G*-values than have been obtained so far. These might come from optimized control of radiation-initiated chain reactions in which radiation can be made to act more specifically and more efficiently.

Lower costs. At present one can estimate the total cost of radiation (including purchase of source, installation, operation, maintenance, depreciation and return on investment) at $2–10/kwh of radiation output. The lower figure applies to 30-kw installations; the higher to 3-kw ones. Accelerators show a slight cost advantage over nuclides. In this size range further cost reductions can be expected through improved design and engineering for accelerators and better shielding and handling techniques for radionuclides.

Probably the largest possible cost reduction is in operator time for acelerators. Salaries for skilled operators presently represent the major cost for these installations. Large cost reduction can come from improved reliability that would permit an accelerator to operate with a minimum of attention.

For very large accelerators or reactor radiation sources (in the order of hundreds of kilowatts) radiation costs in the range of 10 cents/kwh appear possible. This suggests that possible uses in some large-volume processes like rubber vulcanization and petroleum refining might meet economics quite different from the ones that apply now.

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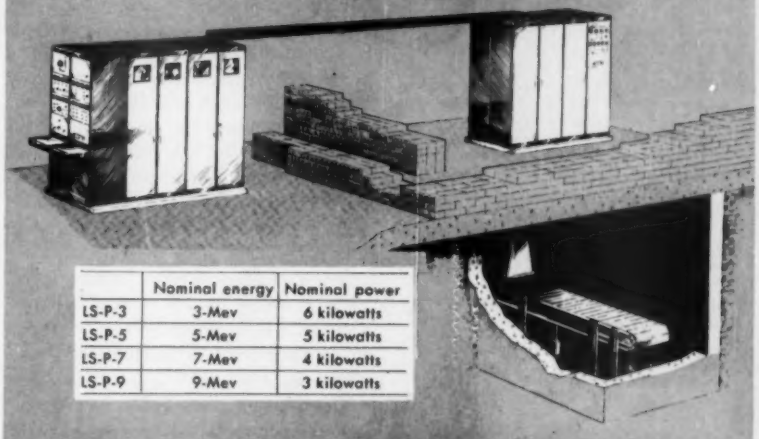

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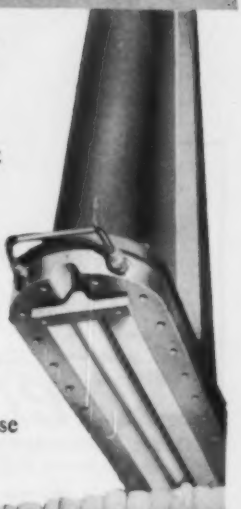

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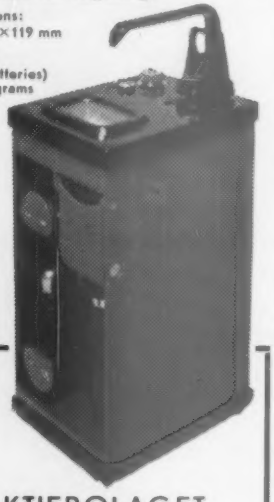

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Low-Level Neutron Dosimetry with Sensitive Foil Methods

By PAUL KRUGER
Nuclear Science and Engineering Corp., Pittsburgh, Pennsylvania

Foil dosimetry techniques have been developed for small neutron fluxes. They were intended especially for measuring neutron levels in spent-fuel food-irradiation facilities and have been used in several of them (*1*). The techniques are generally applicable for all neutron fluxes between 0.5 and 10^4 n/cm²/sec.

Neutron fluxes can be measured in several ways (*2*). A convenient and simple one is foil activation (*3*). Neutrons are allowed to interact with materials of known cross sections, and the flux is determined by measurement of induced radioactivities. This technique is widely used in nuclear reactors and critical facilities where neutron fluxes range from 10^6 to 10^{14} n/cm²/sec. To measure smaller fluxes such as those found in gamma irradiation facilities or outside reactor shielding, special foil techniques and counting methods are required.

Origin of Neutrons

In gamma facilities where fission products are the source of radiation, neutron production is expected from γ,n reactions. This is particularly true of freshly discharged fuel elements in which 12.8-day Ba^{140} has not had time to decay.

Most neutrons are expected from the action of La^{140} photons on deuterium. La^{140} is the short-lived daughter in equilibrium with Ba^{140}. Deuterium is present as 0.015% of the hydrogen in the water in which most spent-fuel elements are immersed for shielding.

About 4% of the La^{140} disintegrations produce 2.5-Mev photons. These produce 150-kev photoneutrons as they interact with deuterium. Threshold for the reaction is 2.2 Mev. La^{140} is the only major fission product during spent fuel use with photon energy greater than this threshold. Since La^{140} is in equilibrium with its parent Ba^{140}, the neutron flux is expected to have an apparent half-life of 12.8 days.

The Argonne National Laboratory gamma facility has reported a background of $\sim 10^3$ n/cm²/sec (*4*). The value for the neutron background at the Materials Testing Reactor gamma facility has been given as $\sim 10^4$ n/cm²/sec (*5*). At the Dugway Proving Grounds facility fuel elements are not

TABLE 1—Properties of Detector Foils

	In	*Au*	*Dy*	*P*	*Al*
Neutron energy	←Thermal and Resonance*→			←——Fast——→	
Activation reaction	n,γ	n,γ	n,γ	n,p	n,α
Resonance energy (ev)	1.46	4.9	—	—	—
Effective threshold (Mev)	—	—	—	2.5	8.1
Isotope produced (half-life)	In^{116m} 54 m	Au^{198} 2.7 d	Dy^{165} 139 m	Si^{31} 2.6 h	Na^{24} 14.8 h
Beta energy (Mev)	1.0	1.0	1.25	1.5	1.4
Beta range (g/cm²)	0.4	0.4	0.5	0.7	0.6
Foil thickness (mil)	5.4	2.0	7.0	100	80

* Resonance measurements are made with indium and gold foils in cadmium covers.

TABLE 2—Neutron Fluxes (n/cm²/sec) in Gamma Facilities

Facility	Irradiation dates (1957)	Thermal flux In	Thermal flux Dy	Thermal flux Au	Thermal flux Average	Epithermal flux In	Epithermal flux Au	Epithermal flux Ratio*	Fast flux P	Fast flux Al
Argonne National Laboratory										
Standard reactor										
	Aug. 6	2,444 ± 10%†			—	5.2	2.6	2.0	—	—
Spent fuel elements in water										
	Aug. 6–8	168	172	160	167 ± 7	4.0	1.0	4.0	—	<15‡
Dugway Proving Grounds										
Co^{60} source	Aug. 13–15	<1	<0.5	<6	<0.5	<0.04	<0.1	—	<100	<15
Spent fuel elements in air										
	Aug. 14–16	4.1	9.9	—	7 ± 3	0.5	—	—	<100	<15
Materials Testing Reactor										
Spent fuel elements in water										
	Aug. 18–20	1,680	1,300	1,310	1,400 ± 200	12	7.1	1.7	<100	<15

* Theoretical value for $1/E$ spectrum is 3.3.
† R. Ringo, Argonne National Laboratory, private communication.
‡ Upper limits of fluxes are based on activated foils for which counting rate was less than 2 cpm.

immersed in water (*6*). The thermal-neutron flux should be too small to measure—less than 0.5 n/cm²/sec.

The La^{140} photoneutron production rate (n/cm³/sec) in ordinary water can be calculated as $q = n\sigma F$. Here n = number of deuterons per cubic centimeter of water ($= 1.0 \times 10^{19}$), σ = cross section for the γ,n reaction of 2.5-Mev La^{140} photons with deuterium ($= 13 \times 10^{-28}$ cm²) (*7*), and F = flux of 2.5-Mev photons (photons/cm²/sec). Thus,

$$q = 1.3 \times 10^{-8}F$$

The thermal-neutron flux produced by a uniform gamma flux in a large volume of water can also be computed. "Large" means that dimensions are large compared with the slowing-down length of the photoneutrons.

At equilibrium the loss of neutrons through thermal absorption by the moderating medium is equal to the production rate. Thus $q = \phi_{th}\Sigma_a$ where ϕ_{th} = thermal-neutron flux (n/cm²/sec), Σ_a = macroscopic absorption cross section ($= 0.017$ cm^{-1}) (*8*). Thus,

$$\phi_{th} = 7.6 \times 10^{-7}F$$

A review of the assumptions helps to estimate the usefulness of these equations. It was assumed that (*a*) the fast-neutron flux results from a uniform gamma field, (*b*) the neutrons are thermalized in a large volume of water, (*c*) the resulting thermal-neutron flux is uniform and (*d*) the neutron multiplication is negligible.

Calculations of gamma fluxes have been made with data for MTR fuel elements given elsewhere (*9*). A fuel element that has reached saturation for Ba^{140} will, on removal from the reactor, have a field of 2.5-Mev gamma radiation given approximately by the expression $F(r) = 4.9 \times 10^9 e^{-0.043r}/r^2$.

$F(r)$ is the flux of 2.5-Mev gamma photons at a distance r from the surface of the fuel elements ($r > 1.5$ cm). Apparently assumption *a* of uniform gamma flux is not entirely valid since the flux falls off with increasing r. However, the volume can be computed for which photoneutron production is within 0.1% of the flux at the fuel-element surface by letting $e^{-0.043r}/r^2 = 0.001$. The value for r is approximately 20 cm or 8 in. Since the irradiation center at ANL is about 5 in. from the fuel-rod center (*4*) and the irradiation center is within an array of rods, assumption *a* can be considered adequate for this configuration. Since the range for neutron production is roughly 20 cm, and the slowing-down length is ~5.74 cm (*10*), assumptions *b* and *c* concerning water volume and uniformity of thermal flux can be considered valid. Assumption *d* concerning neutron multiplication is also valid since the cadmium lining absorbs most of the thermal neutrons near the fuel elements.

A simple calculation of thermal flux in the ANL facility gives a value that is not inconsistent with the reported value of ~10^3 n/cm²/sec.

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from the $D(\gamma,n)H$ reaction with La^{140} photons can be made by observing whether indeed a 12.8-day half-life exists. This requires dosimetry measurements taken over a period of time.

A longer neutron half-life should result if beryllium is present. The photoneutron threshold would be lowered to 1.6 Mev. As a result fission products with photon energies between 1.6 and 2.2 Mev would contribute to the neutron production. Many of these have longer half-lives than Ba^{140}. Thus half-life of the neutron flux would become intermediate between the 12.8 days of Ba^{140} and the effective half-life for the total gamma dose rate.

Dosimeter Foils

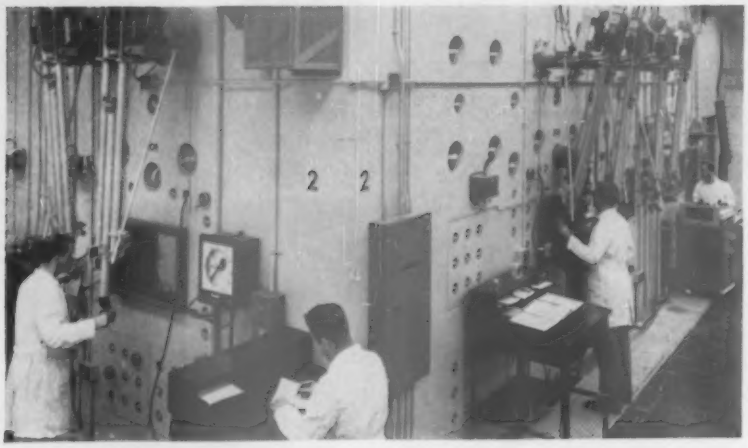
Foils were designed to measure the three general neutron-energy ranges: thermal, epithermal or resonance, and fast.

Since the neutrons produced in gamma facilities have energies less than 150 kev, attention was focused on thermal and resonance-energy neutrons. Indium, gold and dysprosium-oxide foils were used for these regions. To show the fast-neutron flux was too small to measure, phosphorus and aluminum foils were used. Characteristics of all of these foils are shown in Table 1.

Dysprosium has no prominent activation peaks for resonance neutrons. Thus it is an excellent monitor for thermal neutrons. With the cadmium-ratio technique indium and gold foils give measurements of thermal and resonance-energy flux. In view of their respective induced half-lives indium is useful for flux measurements of irradiations of up to ~2 hr, and gold for longer irradiations up to ~5 days. They can be irradiated to saturation to increase sensitivity if no appreciable variations in flux occur during the irradiation.

Indium and gold were both procured as metallic foils. Dysprosium-oxide foils were used when a supplier failed to produce aluminum-flashed metallic dysprosium foils in time for the measurements. Cadmium covers were used for resonance-energy irradiations.

All the foils were 1 in. in diameter to standardize counting geometry. The induced beta energy in all three foils is approximately the same (Table 1). Thus it is possible to make the self-absorption correction nearly the same for all three kinds by using a constant ab-



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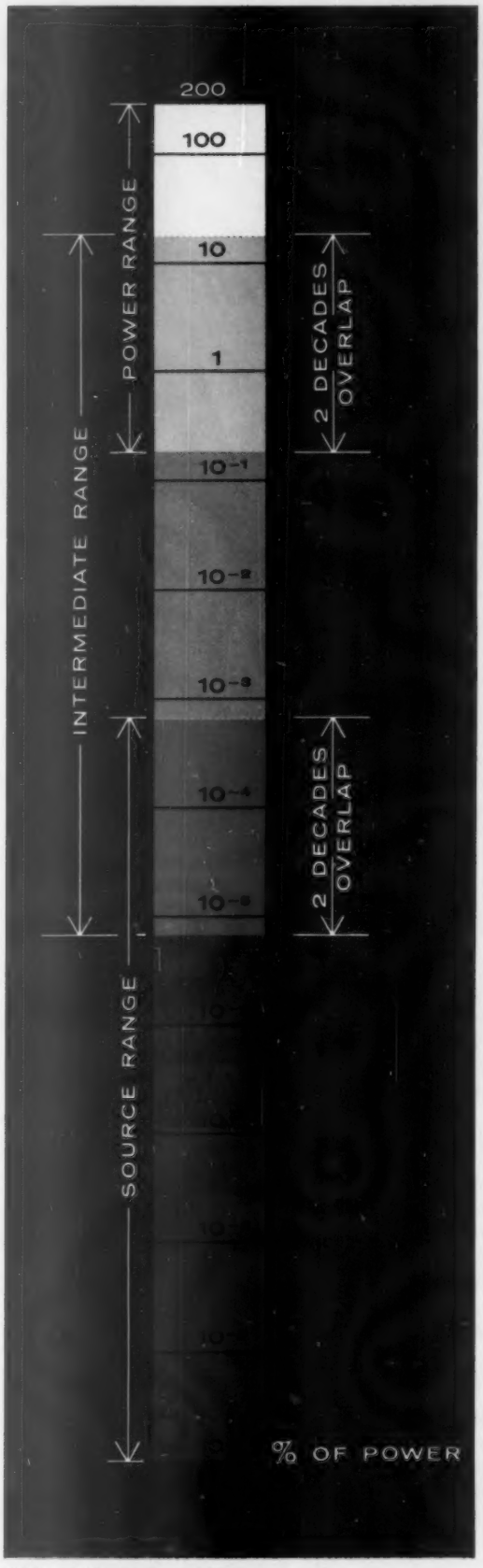

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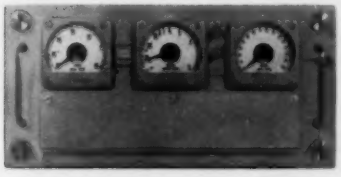

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sorption thickness. A thickness of 100 mg/cm² was chosen; corresponding thicknesses for the foils are 5.4 mil for indium, 2.0 mil for gold and 7.0 mil for dysprosium oxide.

To give stability to the foils and allow either beta or gamma counting, the foils are encased in aluminum holders. The thick side of the case, through which gamma rays are counted, is $\frac{3}{32}$ in., the range of a 1-Mev beta particle. The thin side of the case, through which beta particles are counted, is a 1-mil aluminum foil that keeps the foil in a fixed geometry.

Foils of phosphorus and aluminum were used as threshold detectors to show the absence of fast neutrons. The foils were 1.5 in. in diameter to fit the same counting arrangement as the aluminum-cased foils for thermal and resonance measurements. The use of such foils as dosimeters for low-level fast-neutron fluxes will be covered in a subsequent paper.

Measurements

Measurements were made by foil activation at several spent-fuel facilities. They were part of a program performed for the U. S. Army Quartermaster Corps's Food and Container Institute to study the neutron problems associated with food sterilization (*1*). Maximum sensitivities of the low-level neutron dosimeters were calculated for activation measurements at the Dugway Proving Grounds large Co^{60} source (*11*). Since the Co^{60} photon energy is below the threshold for neutron production in deuterium, no measurable activity was expected. Values of minimum detectable neutron fluxes are calculated from the minimum detection level of the foils.

For irradiations the foils were contained in sealed cans similar in size to the cans of food being irradiated. At Dugway, where the fuel elements are in air, water and organic wrapping were added to the cans containing the foils to simulate atomic composition of foods.

Irradiations and measurements were made at the following facilities: the Argonne National Laboratory spent-fuel facility, the Argonne Standard Reactor (sigma pile) for foil calibration, the Dugway Proving Grounds spent-fuel facility, and the Materials Testing Reactor spent-fuel facility.

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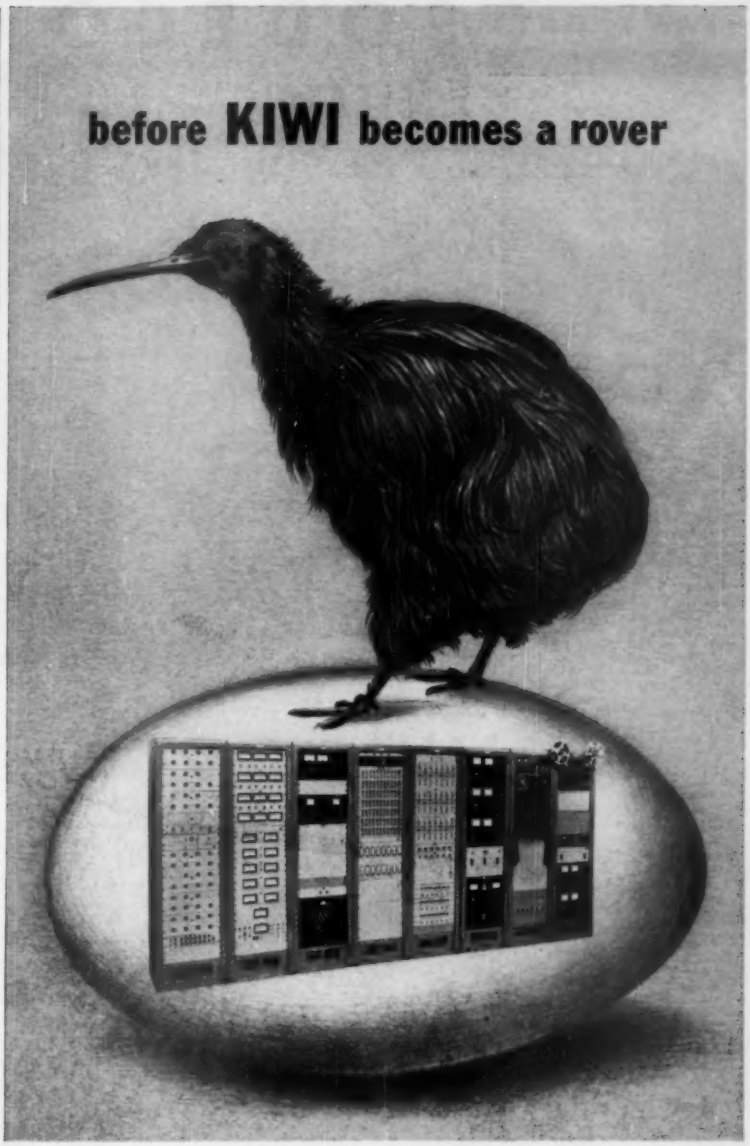

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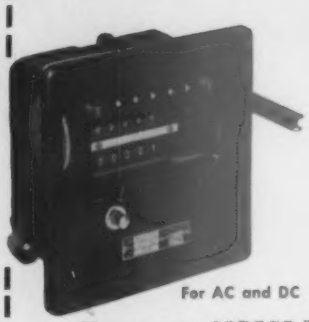

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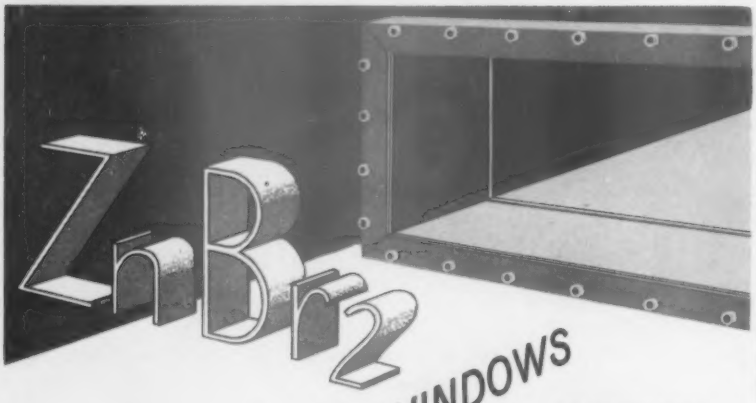

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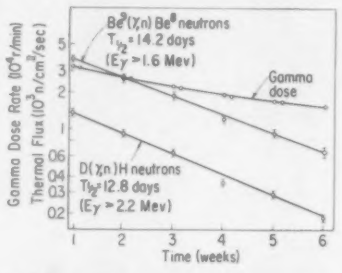
overnight irradiation and exposed in each case to a gamma dose greater than that required for sterilization. On removal from the facilities cans were opened and radioactivity measurements (half-life and beta energy, where possible) were made of the activated foils.

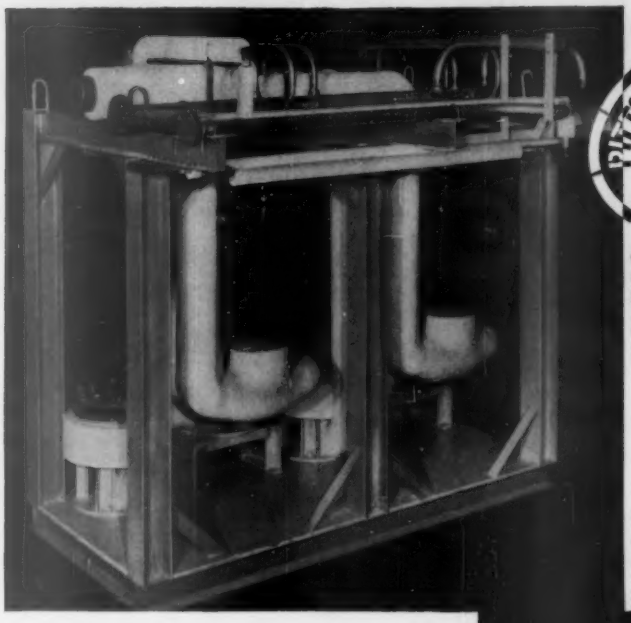
For absolute flux measurements, foils were irradiated in a known thermal flux at the Standard Reactor. To relate fluxes measured at various facilities, all radioactivity measurements were made under fixed counting conditions. A portable low-background (10 cpm) end-window, methane-flow proportional counter with associated shielding, electronics and gas supply went to each site to supply fixed counting conditions.



DECAY RATES for gamma and neutron fluxes at ANL confirm hypothesis that neutrons come from deuterium in water and La^{140} photons. Addition of beryllium permits lower-energy photons to release neutrons

To measure apparent neutron-flux half-life, gold foils were irradiated over a period of six weeks at ANL. Two positions in one irradiation urn were used. In one position gold foils were irradiated in water; in the second, a lower-intensity field was used to irradiate gold foils sandwiched between beryllium wafers. To ensure meaningful results, the irradiations were performed over a period when the fuel-element array was kept constant. Thus there was no fear of effects from varying several parameters on which induced activity depends: (1) the amount of deuterium present, (2) the neutron moderation of the beryllium, and (3) burnup and age of the fuel elements.

Overnight irradiations of gold foils were made once a week for six weeks, and on the succeeding nights cadmium-covered foils were irradiated in the same positions to obtain cadmium



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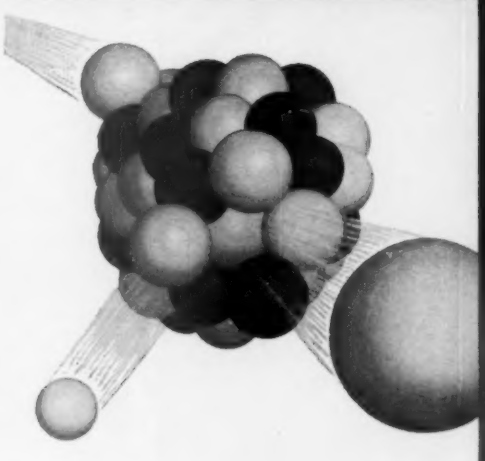

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ratios. After the irradiations gold foils were shipped to Pittsburgh by air for immediate measurement of the 2.70-day Au^{198} activity with low-background counters. Thermal-neutron fluxes from moderated neutrons produced at thresholds of 2.2 Mev and 1.6 Mev were measured as functions of time.

Results

Table 2 presents the data obtained at several gamma facilities. The thermal-neutron fluxes were calculated from the known thermal flux of the ANL Standard Reactor where the foil calibrations were performed. Cadmium ratios were obtained in each facility, and the thermal-neutron flux was calculated. Epithermal fluxes were calculated from cadmium-covered saturation activities, cadmium ratios, and constants given for indium and gold in Table 1. No activity was observed in foils used for fast neutrons. Upper limits for fast flux are assigned on the basis of a minimum detectable counting rate of 2 cpm. The limits are 100 n/cm²/sec above 2.5 Mev and 15 n/cm²/sec above 8.1 Mev. The upper limit for irradiation with Co^{60}, in which photoneutrons are not expected, is 0.5 n/cm²/sec from measurements with dysprosium-oxide foils.

Absolute uncertainties are difficult to assign to the values given in Table 2. For total-flux measurements, at least two foils of each element were used. For epithermal measurements, one, two or three foils of each element were encased in the cadmium shields and irradiated simultaneously. The saturation specific activity of the foils of each element generally agreed within 5%. The uncertainty of the thermal flux in the ANL Standard Reactor was given as ±10% (*12*). The spread in the measured thermal fluxes ranged from 5 to 43%, the higher value for the lowest measured thermal-neutron flux, 7 ± 3 n/cm²/sec. In general, apart from uncertainties from self-shielding of the foils, the fluxes are considered to have uncertainties of the order of ±30%.

The epithermal fluxes have rather large uncertainties since measured activities in most cases were relatively low—ranging from 4 to 400 cpm. The ratios of the fluxes at the resonance energies were compared with the ratio expected with a $1/E$ spectrum. Within the uncertainties of the measurements,

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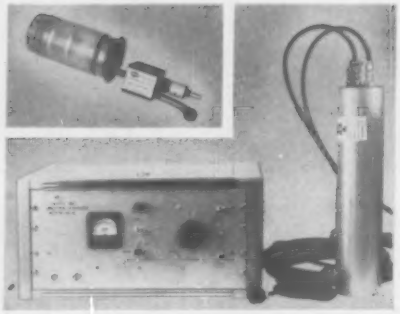

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the resonance spectra in the Standard Reactor, the ANL gamma facility and the MTR gamma facility are consistent with a $1/E$ spectrum.

Since the energy of neutrons from La^{140} photons and deuterium is only 150 kev, neutrons are not expected above this energy. Although upper limits for fast fluxes are given as 100 and 15 n/cm²/sec for effective threshold energies of 2.5 and 8.1 Mev, respectively, fast-neutron fluxes are believed to be entirely negligible—less than 1 n/cm²/sec.

Apparent thermal-flux half-lives were determined and compared with the half-life of the total gamma radiation. The data are shown in the figure on page 122. Thermal neutrons produced by photons of energy greater than 2.2 Mev show a distinct half-life of 12.8 days, as hypothesized. Except for one measurement the accuracy is within ±2%, which is the spread in the cadmium ratios. The one measurement that deviates from the 12.8-day half-life has a cadmium ratio of 3.3, 10% different from the other cadmium ratios of 3.6.

The thermal neutrons produced by photons of energy greater than 1.6 Mev also show a distinct half-life—14.2 days—over the six-week period. This shows that a large fraction of the neutron production results from 2.5-Mev La^{140} photons with smaller contributions from longer-lived fission products that have photon energies >1.6 Mev. The total gamma dose rate exhibits the expected decay over this time period having an initial slope corresponding to a 20-day half-life and a final slope corresponding to a 40-day half-life.

Since thermal flux decays with a 12.8-day half-life, fluxes given in Table 2 are actual fluxes only during the period of measurement. The neutron flux pattern will vary with burnup of fuel elements (until the Ba^{140} reaches saturation), the length of time since the fuel element has left the operating reactor, and the distribution and relative age of the fuel elements in the array. These fluxes generally should be used only as order-of-magnitude values for each facility. The thermal-neutron flux can be conveniently measured at any time with the techniques given in this paper.

* * *

The author gratefully acknowledges the assistance and cooperation of George E. Danald and Daniel Farkas of the QMFCI

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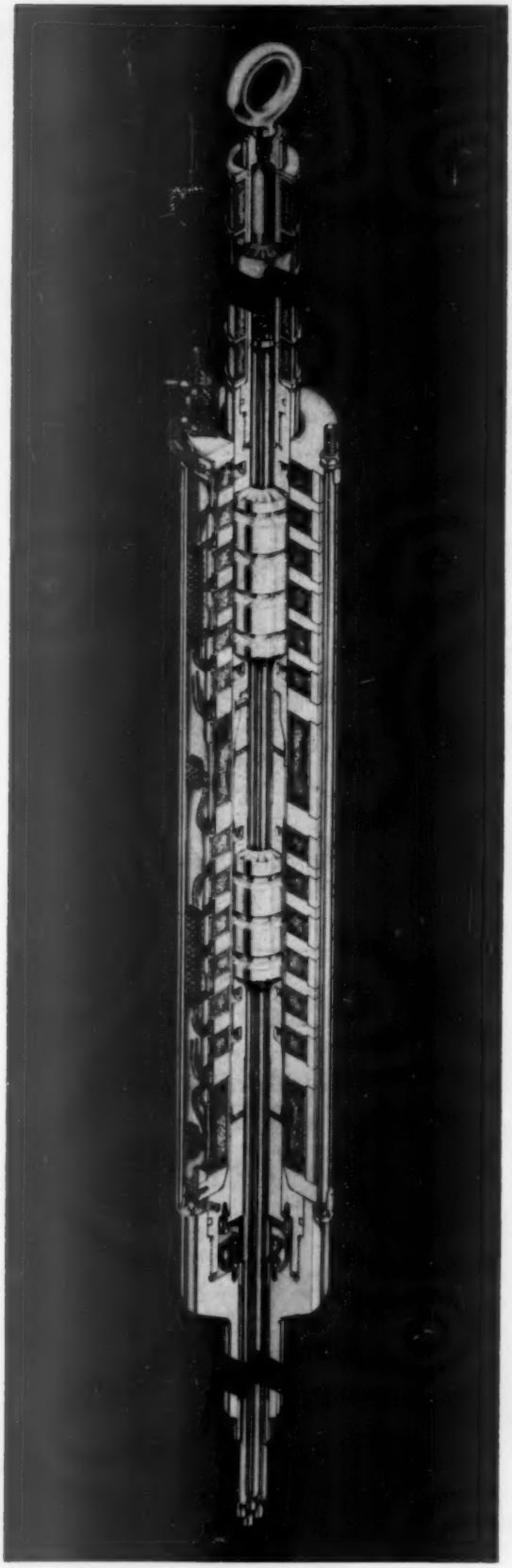

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throughout the course of this program and the assistance of Charles Stanley of NSEC in making the measurements. Acknowledgment is also given to Miss Gladys Swope, ANL; Roy Ringo, ANL; Joseph P. Berg, Jr., DPG; and G. R. Archibald, MTR; and their respective staffs, for their kind assistance in making the several irradiations possible.

This paper reports research undertaken in cooperation with the Quartermaster Food and Container Institute for the Armed Forces Quartermaster Research and Engineering Command, U. S. Army, and has been assigned #955 in the series of papers approved for publication. The views or conclusions contained in this report are those of the author. They are not to be construed as necessarily reflecting the views or endorsements of the Department of Defense.

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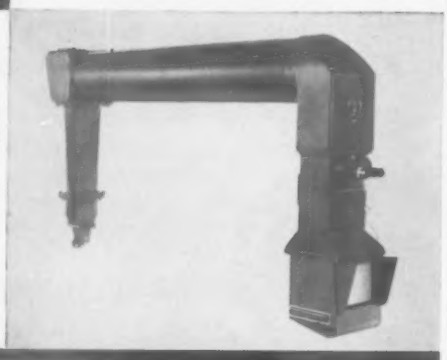

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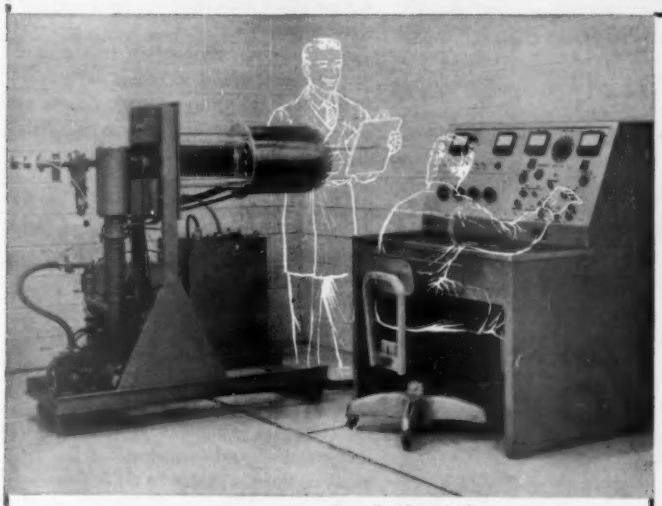

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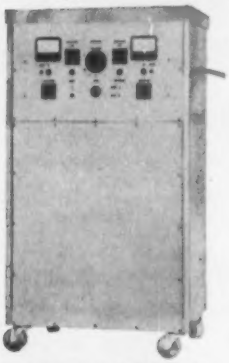

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BOOKS

Chemical Processing of Nuclear Fuels

By F. S. MARTIN and G. L. MILES (Academic Press, New York, 1959, 242 pages, $7.50)

Reviewed by C. E. STEVENSON, Atomic Energy Div., Philips Petroleum Co., Idaho Falls, Idaho

This book is an excellent summary of the present status of methods developed for the chemical processing of spent nuclear reactor fuels to recover fertile or fissionable materials. It is not, however, a detailed reference work on this subject. In all cases it covers broadly, but briefly, what has become an extensive scientific field. It is primarily concerned with basic considerations of nuclear fuel cycles and with the chemical bases of the processes discussed. It has little to say about the technology involved in chemical plant construction and equipment.

The arrangement of the text is logical but fairly conventional. The first part outlines the distinctive characteristics of nuclear as opposed to conventional fuels for power generation and provides the basic nuclear data pertinent to fuels and products of the fission reaction. This is good background material, which those concerned with fuel processing often do not have readily at hand. Considerable familiarity with reactors and the fission process is tacitly assumed, however. Typical fuels are too briefly described, considering their importance to the later discussion. Process requirements and economics are discussed very generally.

The second part describes most of the aqueous processes developed up to this time and outlines pertinent solution chemistry and the physical basis of the solvent-extraction operation. It is by no means a complete discussion of this subject, however, as is evidenced by failure to discuss, for example, the triglycol dichloride process, the fact that diluents other than hydrocarbons can be used with tributyl phosphate, and auxiliary decontamination steps than can be used with solvent processes. The treatment of aqueous processes is, in general, rather cursory, considering the wealth of information that has more recently become available.

In the third section, devoted to nonaqueous processes, considerable detail is given on the experimental data that support proposed process methods. This is perhaps because there is little other information available, as these processes are largely still in the laboratory development stage. Some possible applications of these methods are pointed out.

Radioactive effluent treatment and disposal are given a broad summary treatment in the fourth section. Long-term storage and disposal hazards are carefully set forth.

The final section, which attempts to predict trends in nuclear fuel processing, is of particular interest at this time. No particularly novel conclusions are drawn, however, but it is worthwhile to note the authors' statements that in the future partial decontamination processes and processes capable of handling a diversity of fuel elements will be needed. Further, they attempt to analyze "throw-away" fuel cycles and conclude that, in general, these will not be truly practicable. They also conclude that techniques for conversion of liquid fission-product effluents to safer and more stable solid forms require advancement.

This volume will probably be of most use to technical people with some background in the nuclear field who are becoming engaged in fuel processing studies, or to those in one area of the processing field who wish to broaden their understanding. The book is well prepared and appears to be substantially free from significant errors. The 238 references given are an indication of the magnitude of this field. However, grouping of references for each of the four major parts at the end of each part is quite inconvenient, as it is quite difficult to locate the reference lists. A spot check of the references indicated that they are accurate and reasonably complete up to early 1957.

Introduction to Neutron Physics

By L. F. CURTISS (D. Van Nostrand Pub. Co., Princeton, 1959, 380 pages, $9.75)

Reviewed by JOEL W. CHASTAIN, Jr., Battelle Memorial Institute, Columbus, Ohio

This book is probably worth the purchase price to have available the information in chapter 7, *Calibrations and Standards*. This chapter is probably the most up-to-date collection of information in existence on these subjects and is clearly written with sufficient detail to be useful to an experimenter.

The first chapter is an introduction

to neutron physics and contains the usual information on discovery, properties, definitions, etc. The second chapter is on particle and nuclear interactions and is an easily read summary on cross sections, level widths, independent particle model and other related items. The book includes chapters on neutron sources (including reactors), detection methods, and spectrometers and monochromators.

The material is presented at about a college senior level (as I recall a senior level), which is about right as a reference book for most people who have been out of school over five years. A large number of references, particularly to journal articles, are included, which is another asset of the book.

The book is a worthwhile addition to a personnel or a scientific division library.

Handbook of the Atomic Energy Industry

SIDNEY JEFFERSON, editor (Pitman Pub. Corp., New York, 1958, 270 pages, $8.50)

Reviewed by STANLEY B. ROBOFF, Sylvania-Corning Nuclear Corp., Bayside, N. Y.

This handbook is essentially a compilation of fundamental articles on many of the key subjects of nuclear energy. Included are technical, administrative and industrial subjects.

The book is subdivided into nineteen articles or sections, each prepared by a specialist. The sections discuss the organization of atomic energy authorities throughout the world; education and training programs of the British atomic energy authorities; the history of nuclear energy development; data on nuclear fuels; nuclear reactors in general; aircraft reactors; marine reactors; reactor physics; atomic energy metals and materials; nuclear research machines; radioisotopes and their applications in industry, medicine, biology and agriculture; radiation hazards, protection and detection; and, finally, the handling and disposal of radioactive materials.

To cover such a broad scope in depth undoubtedly would require a series of volumes. Since this handbook comprises only 265 pages, it is quite clear that only fundamentals in each category can be discussed. Furthermore, the material is necessarily limited to broad and simplified discussion and will, therefore, not be useful for

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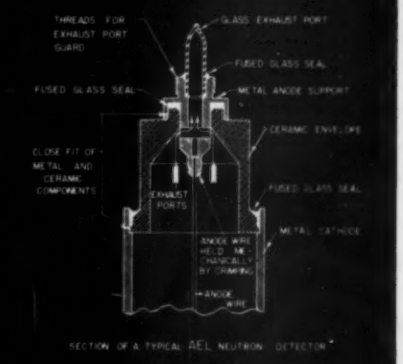

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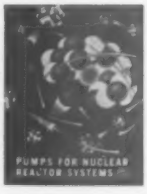

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BOOKS

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specialists in any one of the disciplines covered.

The handbook should be of particular interest, however, to relatively inexperienced people who are planning a career in nuclear energy or who have recently entered the field. Each subject is covered in sufficient breadth to acquaint the reader with its particular problems; much basic information is presented in tables, drawings and charts. The book also will be of value to those in the administrative areas of atomic energy in that it provides a concise source of data and information quickly and in understandable terms.

It should be noted that, because the volume was edited and published in Britain, heavy emphasis is given to the British program and data derived from this program. However, enough information is given on programs of other countries so that comparisons can be made among them.

BOOKS RECEIVED

Nuclear Spectroscopy Tables, by A. H. Wapstra, G. J. Nijgh, R. Van Lieshout (Interscience Publishers, New York, 1959, 135 pages, $8.90). This compact collection will be a useful member of the reference shelf of many of the world's atomic and nuclear spectroscopists. Its subject areas are *Mathematical Data, Atomic Constants, Elements and Isotopes, Heavy Particles, Electrons, Gamma Rays, X-rays and Auger Electrons, Angular Distributions and Correlations, Nuclear Models* and *Calibration Standards*—RHE.

An Introduction to Transistor Circuits, by E. H. Cooke-Yarborough (Interscience Publishers, New York, 1957, 154 pages, $2.75). Consistently the British set a standard in little books with lots of information. This volume starts with the nature of semiconduction and goes to transistors in computer circuits in its short length.

Introduction to Nuclear Power Costs, by Arnold Rochman (Simmons-Boardman Pub. Corp., New York, 1959, 50 pages, $2.95). The idea of publishing monographs on nuclear topics is a good one, particularly for the subject "Nuclear Power Costs."

The author's approach and coverage appears well thought out. However, many of the references go back as far as 1946 and none of the cost data seems

to be newer than 1955. A better text could have been written using newer data and showing more of the procedures for making nuclear-power-cost calculations. Surely, the economics data that has been developed in the past two years has a much stronger basis in fact than any generated prior to that time.

An added inconvenience is the variety of equivalent parameters used, necessitating conversion from one system to another to make comparisons.

Nuclear Engineering Handbook, Harold Etherington, editor (McGraw-Hill Book Co., New York, 1958, 1857 pages, $25.00). *To be reviewed.*

Organic Syntheses with Isotopes, by Arthur Murray III and D. Lloyd Williams (Interscience Publishers, New York, 1958, 2096 pages, $25.00 each for Parts 1 and 2). *To be reviewed.*

ALSO OF NOTE

Radiations from Radioactive Atoms in Frequent Use, by L. Slack and K. Way. This carefully prepared and referenced compilation is particularly intended for dose calculations required in biological and medical work. It was supported by the AEC Div. of Biology and Medicine. Energies and intensities of all particle and electromagnetic radiations, as well as orbital-electron emissions following the primary nuclear transformation, are given for eighteen of the most frequently used radioisotopes. In an effort to promote greater consistency in the radiobiological field, the most accurate data reported in the literature was used. Information includes decay scheme; particle spectrum, energies, intensities and range in water; and dose-rate graph, energies, intensities and half-thicknesses of electromagnetic radiations. 75 p. *U. S. Government Printing Office, Washington 25, D. C., 55¢.*

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Write for literature and state the nature of your detection requirement so that we may promptly send you proper information, at no obligation, of course.

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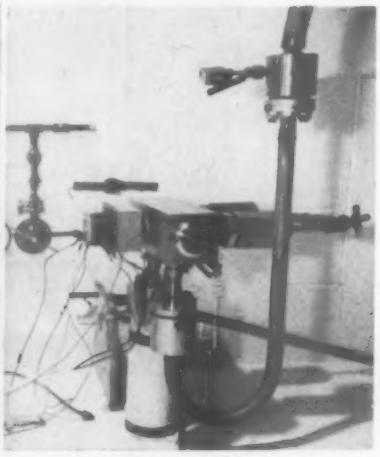


ASCO Sets Up Test Loop for Solenoid Valves

A test loop has been placed in operation to test solenoid valves for reactor applications at the Automatic Switch Company. The loop is capable of providing circulating water at 3,000 psi and 550° F. With this all-stainless-steel test loop, engineering and production tests can be made on a wide variety of valves under service conditions simulating those encountered in pressurized-water reactors, so that the effects of high temperature, high pressure, thermal shock and corrosive media on valve structures and solenoid operation can be determined. The instrument panel for the loop (above, left) indicates temperatures and pressures at various points in the loop and provides for complete control of loop operation. Concrete-block walls enclosing the loop provide safety for operating personnel. Tests can be completely controlled from outside the enclosure. Shown undergoing tests (above, right) is a four-way valve designed to control the main cylinder-operated isolating (stop) valve in reactor primary-coolant loops. This stainless-steel, hermetically sealed valve features exceptionally tight seating through beveled, poppet-type seats and discs. Solenoid-pilot controlled, and available with manual override, it is supplied in 1-in. size. This unit is suitable for 2,500 psi differential pressure at 600° F. ASCO two-, three- and four-way valves have been specified for primary and secondary systems of reactors, as well as for instrumentation control.—Automatic Switch Co., Hanover Rd., Florham Park, N. J.

Neutron-Detection Foils

Gold foils 0.500 in. in diameter by 0.002 in. thick, weighing 0.12 gm with Pt and Ag impurities less than 0.01 wt% are offered packaged between 0.030-in.-thick 99.999%-pure aluminum discs pressure-welded about periphery. Also available: cobalt foils 0.500 in. in diameter by 0.004 in. thick and weighing 0.11 gm; uranium foils 0.250 in. in diameter by 0.020 in. thick with 0.4039 wt% U^{235} encased in pressure-welded aluminum package; 99.999%-pure aluminum foils 0.750 in. diameter by 0.030 in. thick and weighing 0.585 gm.; sulfur foils 0.750 in. in diameter by 0.250 in. thick, encased in aluminum cup with ring cover. In sulfur foils 92% sulfur (99.99% pure) is mixed with graphite (8%) for elimination of static charge build-up.—Aerojet-General Nucleonics, P. O. Box 77, San Ramon, Calif.

Ionization-Detection Systems

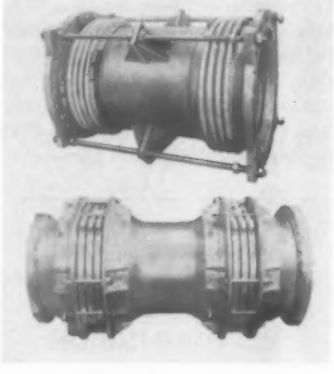
Model 10 and Model 20 are ionization-detection systems for automatic gas-liquid chromatography. Model 10 is permanent-installation, laboratory-system capable of either single- or dual-column operation using glass, metal, or capillary columns. Model 20 is portable system using capillary tubes. Features of Model 10 include: relative insensitivity to changes in gas flow, temperature and pressure because ions produced in chamber are collected at electrode rapidly (within 10^{-3} or 10^{-2} sec); sample-collection system built around low-internal-volume miniature manifold valve that allows for individual collection of at least five different components emerging rapidly from column (within 10 sec of one another, if necessary).—Wheelco Instruments Div., Barber-Colman Co., Rockford, Ill.

Radiation Warning Signs

Metal radiation warning signs that are completely weatherproof and heat-resistant, have porcelain enamel finish. Model WP-41 metal "Caution . . . Radiation" signs are designed to fire department specifications and will withstand intense heat up to 1,600° F. Magenta and yellow color combination meets AEC regulations.—Atomic Accessories, Inc., 244-02 Jamaica Ave., Bellerose 26, N. Y.

Irradiation Services

Irradiation services with the Dynamitron accelerator (NU, Nov. '58, 213) are now available. Irradiation center contains two separate vaults with Dynamitron electron accelerator units of 1-Mev, 2-kw and 1.5-Mev, 15-kw output. The energy output of the larger unit is equivalent to approximately 10^6 c of cobalt-60; upon conversion to X-rays, the flux is similar to that from 300,000 c of cesium-137. Both units are available for contract work on single or sustained basis. In addition, research assistance can be provided.—Radiation Dynamics, Inc., Westbury Industrial Park, Westbury, N. Y.



Expansion Joints

Line of bellows-type expansion joints (above) accommodate pipe movement in any direction. Basic elements of these units include two hydraulically-formed bellows, a center section of pipe

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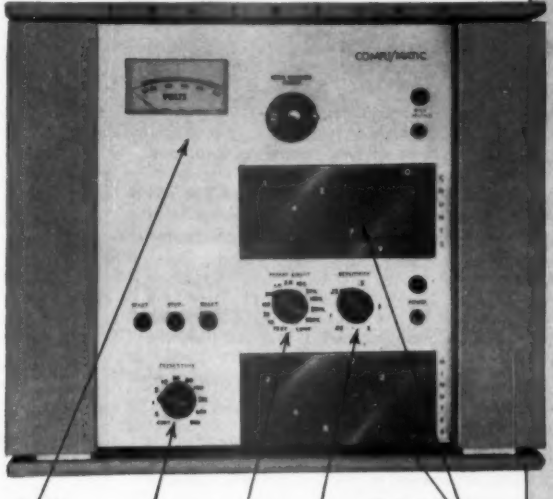

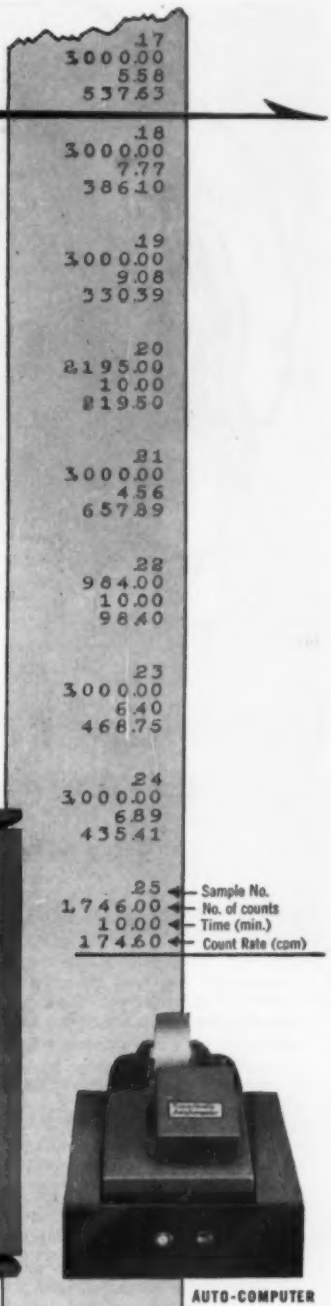

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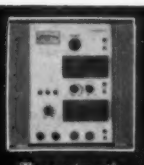

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Streaking Pipette

Model 1860 chromatography streaking pipette (above) ensures uniform distribution of sample along line of origin in streak application. Design eliminates drop formation at tip of pipette and maintains constant hydrostatic head during delivery of entire sample. Volume of ~0.3 ml can be applied by pipette with one filling.—Research Specialties Co., 200 S. Garrard Blvd., Richmond, Calif.

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Fission-product ion-exchange water monitor is connected to sampling line from main coolant stream of reactor. Instrument uses ion-exchange-resin columns to separate iodine fission products from main coolant stream. By energy discrimination, each iodine isotope is looked at individually, and iodine isotopes only. Only two connections are required. Instrument is for pressures exceeding 2,500 psi and is sensitive to 11,000 cpm per μcurie of I^{135}, with a background of 125 cpm.—

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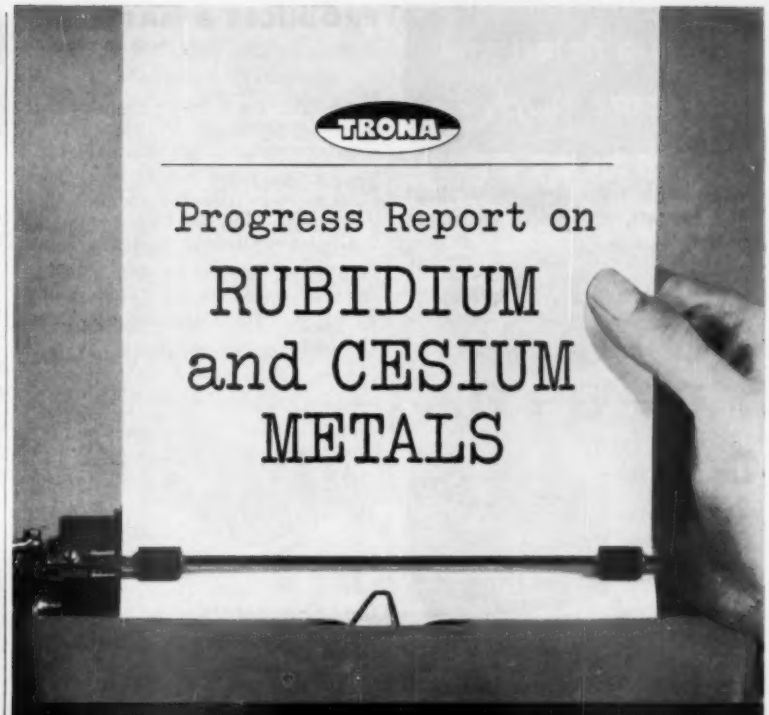

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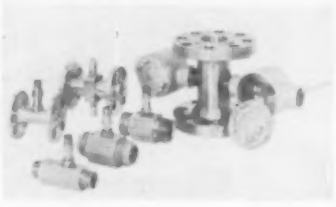
PRODUCTS & MATERIALS

Department starts on page 136

Tracerlab, Inc., 1601 Trapelo Rd., Waltham 54, Mass.

Boron-Steel

Type 304L stainless steel containing 2%-boron melted in electric arc furnaces is commercially available in two rectangular shapes: 6 by ⅜ in. and 3 by ⅜ in.—The Carpenter Steel Co., Reading, Pa.



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Portable X-Ray Spectrograph

Norelco portable X-ray spectrograph consists of two units: (1) gaging or detector head containing X-ray source, detector and ratemeter, which weighs ~18 lbs, and (2) power supply/electronic chassis requiring ~200 watts of energy from 115- or 230-v, 50- or 60-cycle a-c source via cord and plug, which weighs ~48 lbs. Inverter can be used for operation on 6- or 12-v storage battery when desired.—Philips Electronics, Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.

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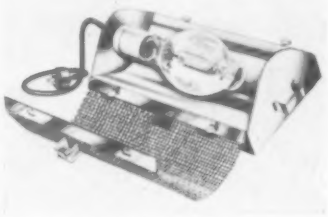

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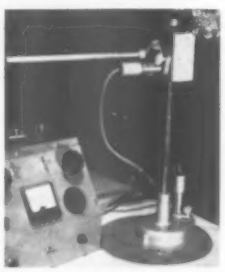

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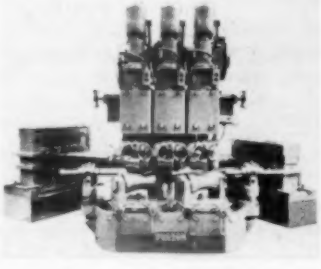
Scintillation Counter

Model 10-7 is low-noise, high-speed counter for X-ray diffraction studies. Monitoring flanges are available to match counter to standard commercial X-ray diffraction systems. Unit includes gain of 10 preamplifier, selected photomultiplier tube and specially fabricated, thin NaI(Tl) crystal.—Radiation Instrument Development Laboratory, Inc., 5737 S. Halsted St., Chicago 21, Ill.



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Series of 5-roll, rotary bar and tube straighteners (above) are equipped with patented Syncro-Drive, which provides entirely guideless, precision straightening at high production speeds. They are available in all sizes for tubes from 1/16- to 6-in. o.d. and bars from 1/16- to 4-in. diameter in all metals.—Sutton Engineering Co., First National Bank Bldg., Pittsburgh 22, Pa.

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Metal fabrication facilities	8 pp.	Form No. RL558	Smithcraft Fabrication Div., A. L. Smith Iron Co., 200 Bent St., Cambridge, Mass.
Nuclear instrumentation	4 pp.	Bulletin 3015	Consolidated Electrodynamics 300 N. Sierra Madre Villa, Pasadena, Calif.
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Mass Spectrometers	16 pp.	Bulletin 1824C	
Activities and products	2 pp.	"Nucleonics Markets" reprint	Bar-Ray Products, Inc., 209 25th St., Brooklyn 32, N. Y.
Radiation monitoring	24 pp.	Pamphlet No. P-31	Eastman Kodak Co., Rochester 4, N. Y.
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Reactor control systems	18 pp.	Publication N-03(1)	Leeds & Northrup Co., 4934 Stenton Ave., Philadelphia 44, Pa.
Organic-moderated reactor	24 pp.	"Organic Reactor"	Atomics International Div., North American Aviation, P. O. Box 309, Canoga Park, Calif.

mize base-line shift at high-duty cycles. Over-all gain of amplifier is 70,000 with stability of 0.9% for line voltage changes from 105 to 130 v. Maximum rate is 250,000 cps.—Franklin Electronics, Inc., Bridgeport, Pa.

Bf_3 Counter

Pencil-size Bf_3 counter (above) is 6 in. long with ½-in. diameter. It has 2⅛-in. active anode and 0.032-in. brass walls. Counter has approximate operating region of 900 v, typical plateau length of 150 v and average plateau slope of 3% per 100 v.—Radiation Counter Laboratories, Inc., Skokie, Ill.

Manual Sample Changer

Model 3056 Universal manual sample changer provides lead shielding for detectors to eliminate spurious background radiations. Changer consists of lead detector shield that fits on top of lead base. Heavy base provides additional lead shielding and has two aluminum trays. One tray accepts all popular-sized sample pans, the other accepts radiation-absorber discs.—Nuclear-Chicago Corp., 229 W. Erie St., Chicago 10, Ill.

Air-Sampling Pump

Air-sampling vacuum pump (above), activated by graphite-ringed pistons, is designed for continuous duty. Choice of air capacity is 20 cfm or 4 cfm. All bearings are greased-packed and -sealed; no oil is needed. Inlet and exhaust valves are optically polished to give leakproof fit. Piston-ring joints are self-sealing.—Gelman Instrument Co., 233 Jefferson St., Chelsea, Mich.

parisons do give machines the edge, but only in a broad sense, and not by orders of magnitude.

In summary, the AEC industrial radiation program will establish those conditions that will permit the normal growth pattern in the radiation industry that Dr. Morganstern advocates.

— PAUL C. AEBERSOLD, Director
Office of Isotopes Development
U. S. Atomic Energy Commission
Washington, D. C.

Don't Be Half-Safe

DEAR SIR:

The article by Ernest Siddall, "Statistical Analysis of Reactor Safety Standards" (NU, Feb. '59, p. 64), appeared to me to be so irrational that I feel impelled to reply.

While I am neither a nuclear nor any other kind of physical scientist, my occupation as a lawyer with construction experience and a civil engineering education, employed by a high-risk industry serving the nuclear industry, among others, has given me a familiarity not only with industrial risks in general but also with some of the more important aspects of the nuclear risks.

There are some statements made by Mr. Siddall in his article that simply cannot be supported. For example:

1. "The basic difficulty in thinking about safety is probably a failure to understand that the intrinsic danger of a process has little or no relationship to the effective danger it actually presents. . . . Manufacturing photographic film or fertilizers is about twice as dangerous as making explosives or fuses and powder."

The reason the manufacture of explosives is relatively safe today is that that industry has paid more attention to the safety aspects of production than most other industries and has thereby eliminated many of the hazards that once inhered in the process.

2. "The worst possible misfortune that can befall a person is death, and, unhappily, all people are at all times exposed to a risk of death. . . . Even if there is disability, this can be offset financially, which is not possible with death."

Mr. Siddall considers the injury only from the point of view of the worker, without thought of the effect upon his family or society in general. He apparently has never been confronted with the sort of industrial accident that, for example, produces paraplegia, which not only destroys the ability of the worker to earn a living in his former occupation but also affects his psychological makeup to such an extent that he no longer has sufficient interest or aggressiveness to seek to be rehabilitated. If the author does not know that there can never be a financial offset against serious disability, then the author has never come into contact with a person who has been so disabled. Both the workmen's compensation laws and the general law of torts relating to personal injuries recognize as a basic premise that there can be no "offset" between disability and financial reimbursement.

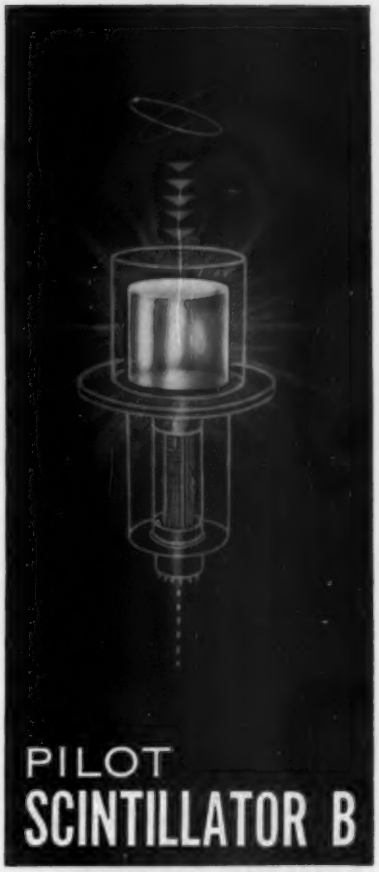
3. "By comparison, injury less than fatal (say within a month) can probably be ignored, since most nonfatal injuries are followed by fairly complete recovery."

As to the latter portion of this statement, see my preceding comments. I am astonished that a person in the nuclear industry, of all persons, should be willing to ignore injuries that do not result in death within a month. I suggest that neither he nor any nuclear scientist is able at this time to give us any quantitative analysis of the effect upon the residents of an urban area of radioactive fallout following a complete rupture of a containment vessel in a nuclear power station during a severe nuclear accident. None would deny, I suspect, that some deaths could result but probably not within the one-month time limitation so glibly suggested by the author.

4. "In general, a large fraction of accidental deaths—and at least some so-called natural deaths—could be avoided if more money were spent on safety measures or if wealth were sacrificed by working more carefully and more slowly or in not carrying out some of the more dangerous operations."

To paraphrase Mr. Siddall, accidents are a price to pay for greater efficiency. Such thinking is representative of those who know least about safety. It has been demonstrated that accidents result from inefficiency, from lack of planning, or from lack of proper equipment. I know of no industry in which the most efficient producer is not a leader in the safety record of that industry.

5. "Fortunately in most western



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NUCLEAR REACTIONS

This department starts on page 6

countries freedom of exchange of money means that such things as pleasure and wealth, at least in the framework of a study like this, can be equated with money."

I doubt that many philosophers will agree with his statement that there is much correlation between pleasure and money, although there probably is a correlation between the pursuit of superficial pleasure and money, but such pursuit is not worth the cost of wasting a single life, as far as I am concerned.

6. "The more numerous accidents of lower degree provide a warning and produce the right attitude of caution toward larger ones."

It may be that the occurrence of less severe accidents will cause employees to develop a cautious attitude, but even this has not been firmly established. The causative factors that work to produce minor injuries are usually entirely different from those that produce major accidents. In our industry, we have found that it is fruitless to preach safety in the abstract, or to assume that, by eliminating one class of accidents, we can affect the frequency of any other class. Our safety program, therefore, is directed toward learning the causes of all different classes of accidents and taking positive steps to eliminate as many of those causes as we can.

7. "Table 3 is a comparison of the relative contribution to the community risk in nuclear and coal power stations."

Table 3 does not show any operating risks. The author implies that the only other risks are those of manufacture and construction of the two types of plant. The risks inherent in the operation of either a hydroelectric or a fossil-fueled steam electrical generation station are extremely small today, while the risks inherent in the operation of a nuclear power generating station have yet to be fully assessed. Certainly the risk in conventional stations is almost exclusively a risk to the few employees of the station, while in the nuclear station the risk spreads across the community in which the station is located. This disparity appears to me to be a conscious misrepresentation by omission on the part of the author.

Perhaps another factor is germane to this discussion, although it, too, has been ignored by the author. Currently neither the United States nor Canada has a crying need for nuclear power. Both hydroelectric and fossil-fueled power stations are far more economical. The hue and cry for acceleration of nuclear power station development in the United States has been generated by (1) public power proponents, (2) politicians who insist that the United States must be superior to Russia in all manner of technical and scientific matters and (3) the heirarchy of atomic bureaucrats and nuclear scientists. A well conceived, thoroughly planned conservative nuclear power development program is desirable, but there is no need, economic or otherwise, to sacrifice conservative safety standards in developing atomic power.

Apart from the article itself, the comments by other atomic specialists are interesting. Mr. Lewis' comment, for example, that a small addition to expense near the threshold of cost can have an adverse effect upon standards of living, while perhaps true as a general statement, appears to be entirely inapplicable to the present discussion because atomic energy has not yet even come close to the cost threshold that obtains in conventional power plants, and I doubt that, even if all safety factors were ignored, the cost could be reduced sufficiently to make nuclear power even slightly competitive with conventional power in the United States or in Canada. Moreover, no one outside the Atomic Energy Commission knows whether the cost of fabricated nuclear fuel furnished by the AEC for power generating stations has been kept artificially low at the expense of the American taxpayers.

Mr. Randers' statement contains an odd reference to "the money so commonly lavished on containment shells." The cost of such containment shells in large nuclear generating stations represents perhaps 2% or 3% of the capital investment in the plant, and this cost could probably be materially reduced by proper planning. Such a small portion of total cost hardly appears to be "lavishing" money on containment shells. If a nuclear station can be made so safe that a containment shell no longer becomes necessary even under the worst accident postulated, that will be fine, but, until that date comes, the slight cost of this last ditch safety device appears

to be well worth incurring. It should be remembered that the containment shell exists simply because of a risk of nuclear contamination of an entire community resulting from the "maximum credible accident," and we all know that sometimes even the incredible occurs.

I am glad that Mr. Beck is chief of the AEC Hazards Evaluation Branch. He appears to have been singularly unimpressed by the article.

—Richard A. Barton, Attorney
1305 W. 105 St.
Chicago, Illinois

Dear Sir:

The letters from Messers. Plumlee (NU, April '59, p. 6) and Barton lead me to suspect that they have not really understood the nature of the nuclear safety problem as it stands at the moment.

I hope that nothing I said implied any condonation of carelessness, and that it will be seen that my economic criterion would automatically mean that any safety measure that would pay for itself in increased output or by reducing compensation and repair costs by an amount greater than its cost would receive my fullest support. Insofar as I implied any changes in safety measures, it was to indicate that we must demand effectiveness in them, and I believe that measures that prevent accidents at source, such as proper design of coolant and instrumentation systems, are essentially better value for money than palliatives such as containment shells, which can only be of value when an accident occurs.

My main theme, however, is to try to discover where we should draw the line in safety measures. Those working on reactor designs will realize that there is no upper limit to spending on safety. Vague exhortations for more safety are therefore of no assistance. What we need to determine is what particular combination of safety measures is needed to put our industry in an acceptable position in respect to safety. No line of reasoning less than that which I have proposed seems to lead to attaining this aim.

Several of the points raised indicate a lack of quantitative precision in my approach. This is a fair criticism, but it is pointless to aim at precision in detail when the whole underlying philosophy still needs to be debated.

—E. Siddall
Atomic Energy of Canada Ltd.
Chalk River, Ontario, Canada

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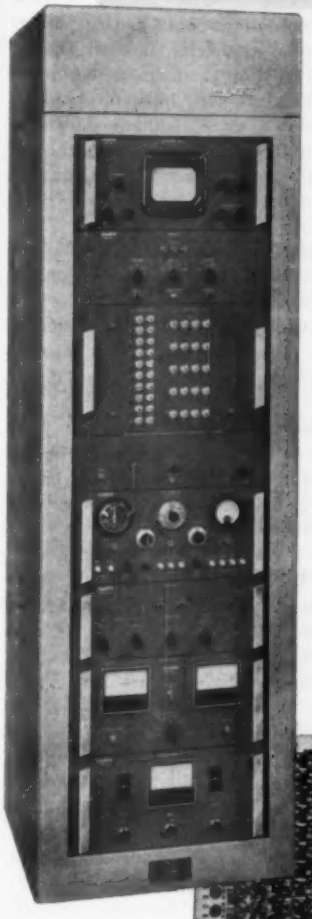

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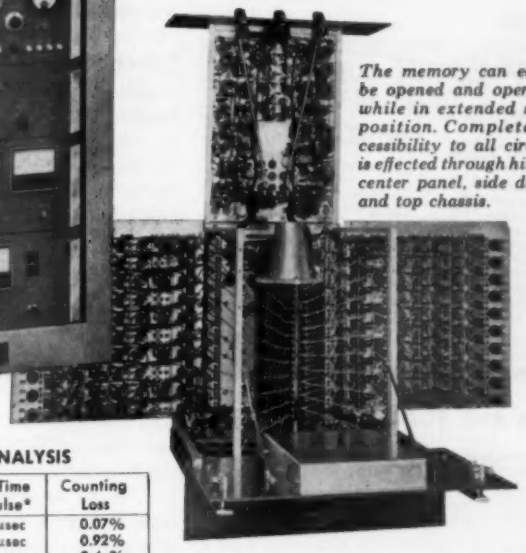

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INDUSTRY NOTES

• **Hughes Aircraft's** Nuclear Electronics Dept. is offering a complete radiation-lab package—planning, design, engineering and construction of facilities and equipment, including an electron linear accelerator producing a short, intense pulse of gamma rays. Hughes is also soliciting orders for neutron generators, pulsed reactors and test reactors.

• **Columbia-National Corp.** is delivering reactor-grade zirconium to AEC at a rate greater than that called for in its five-year, $22,750,000 contract. President Gordon Kiddoo said that growing demand from naval and commercial reactor programs indicates further increases in production.

• **Atomic Personnel, Inc.,** 1518 Walnut St., Philadelphia, has been organized —a personnel placement service for the nuclear field; Arthur L. Krasnow, formerly of Budd Co., Baird-Atomic and Atomic Instruments, is president.

• **Atomic Industrial Forum** has published a directory of products, equipment and services offered by the nucleonics industry (40 major classifications and 130 subcategories).

EXPANSIONS. The tritium-production operation of **United States Radium,** Morristown, N. J., has been moved into a new one-story building adjoining the Bloomsburg, Pa., plant; the move was "a direct result of increased demand" for tritium light sources. . . . **Technical Operations, Inc.,** Burlington, Mass., is adding 5,000 sq ft of lab and office space to handle increasing business from industry, AEC and other government contractors. . . . **Interstate Electronics Corp.,** Anaheim, Calif., has formed a nuclear instrumentation dept. and has opened an office in Tokyo, where the firm might go into limited parts production. . . . **Brush Beryllium** has taken two expansion steps: (1) adding 15,000 sq ft of production space to its Elmore, Ohio, plant; and (2) establishing a production facility and sales office in the San Francisco area; the West Coast plant will produce beryllium components for the reactor and other industries. . . . **Atomic Associates,** Jamaica, N. Y., has opened a Detroit sales office to serve Michigan, Indiana and western Ohio. . . . **Consolidated Electrodynamics,** Pasadena, Calif., has formed an engineering subsidiary, Consolidated Systems Corp., Monrovia; a process systems dept., specializing in nuclear instrumentation and process-control systems, is among the six departments created by the subsidiary.

FOREIGN NOTES. The French firm **Stein & Roubaix,** Paris, will manufacture and market throughout Europe a U. S.-developed consumable-electrode vacuum-melting furnace for zirconium and other "super-metal" alloys; the U. S. firms involved are **Allegheny Ludlum Steel** and **McGraw-Edison.** . . . **Tracerlab** has established a resident engineer in Amsterdam and will begin marketing selected items manufactured there and in the U. S. to European customers. . . . **Isotope Developments Ltd.,** Britain, has reported orders from Poland and Red China and is promoting its products in other Communist-bloc nations.

NEW BUSINESS. December 1959 is scheduled delivery date for a 10-Mev electron linear accelerator sold by **Varian Associates** to the Danish Atomic Energy Commission. To be installed at the Neils Bohr Laboratory, Copenhagen, the machine will be used for research and food processing. . . . The Navy's Bureau of Ships has given **Westinghouse** a contract for design, construction and testing of a 5-kw thermoelectric generator; heat source will be oil, Westinghouse said.

FINANCIAL. Record sales, earnings and backlogs are dominating the nucleonics financial news. **Nuclear-Chicago** reported record sales and earnings for the six months ending Feb. 28, plus a 50% increase in new orders during the period (earnings were $261,853 or 40 cents per share); **Brush Beryllium** reported record sales and earnings for 1958, despite a cut from 100,000 lb/yr to 37,500 lb in its 5-year contract with AEC (earnings were $1 per share); **Victoreen Instrument** claimed record sales and earnings in the quarter ending March 31; **Baird-Atomic** reported a $5-million backlog as of early April—the firm's largest ever. . . . **Beryllium Corp.,** which reportedly took a cut similar to Brush Beryllium's last year, reported '58 earnings of $1.01 per share and predicted '59 earnings of $2.50 per share, first quarter '59 earnings were 58 cents.

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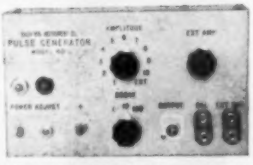

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NUCLEAR CAMPUS

• **Univ. of Wisconsin** is expected to take delivery this summer on a $1-million, 10-Mev tandem Van de Graaff accelerator manufactured by High Voltage Engineering Corp. The machine will be located underground.

• **Campus Reactors. Texas A&M** has applied to AEC for a license to construct and operate its 100-kw, pool-type research reactor—to be built by Convair as part of the college's projected nuclear center. . . . **Ohio State Univ.** has purchased a training reactor from Lockheed Nuclear Products, Atlanta, at a cost of $168,537. . . . The big new research reactor at **McMaster Univ.**, Canada, has gone into operation; the AMF-built facility operates at 1-Mw but is convertible to 5-Mw. . . . **Stanford Univ's.** new 10-kw, pool-type reactor, purchased from GE, will be in use this fall. . . . Helped by an $80,396 AEC grant, **Syracuse Univ.** has bought a subcritical reactor and a reactor simulator.

• **Univ. of Michigan** has launched a campaign to raise $2-million for its Memorial-Phoenix Project—"the largest independent atomic research program in the world," according to university officials. Campaign chairman is James C. Zeder, vice-president of Chrysler Corp., who said the money sought would support the project for five more years. Some $8-million spent since Phoenix was founded in 1948 has made possible a 1-Mw research reactor, extensive additional facilities and 185 research projects.

Courses

The **Gordon Research Conferences** for 1959 will be held June 4–Sept. 4 at Colby Junior College, New London; New Hampton School, New Hampton; and Kimball Union Academy, Meriden; all in New Hampshire. Program is designed to bring experts up to date on latest developments in chemistry and physics, analyze the developments and provoke idea exchanges. **Nuclear chemistry** is being offered June 29–July 3 at Kimball Union Academy.

Nuclear Development Corp. of America has organized a half-day, class-type program in on-the-job **research and development activities in the nuclear field.** Conducted by senior NDA personnel, it is open to seniors and graduates in science and engineering, will be scheduled periodically.

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NEWSMAKERS

In high-level changes at ACF's Nuclear Products-Erco div. **James J. Dickson** has been named reactor engineering manager, succeeding **George A. Anderson,** who is now with Curtiss-Wright (NU, May '59, 210); Dickson's former job as project manager for the Elk River reactor has been filled by **William S. Farmer,** formerly senior nuclear engineer. **R. M. Jones,** marketing manager, has gone to Lockheed, Atlanta, as asst. manager for the commercial nuclear operation.

Two management developments involving the Industrial Reactor Laboratories, Plainsboro, N. J.: **William E. Chamberlain, Jr.,** IRL general manager, has been named a divisional vice-president of the Atomic Energy group, American Machine & Foundry Co.; and **Edward J. Goett,** executive vice-president of Atlas Powder Co., has been elected president of IRL, succeeding Harry L. Hilyard of American Tobacco Co. Chamberlain, who is also general manager of AMF Atomics div., has been in the nucleonics field for many years, including five at General Dynamics, where he participated in the *Nautilus* program.

Chamberlain

Goett

Fred Hittman has been picked by Martin Co.'s Nuclear div. to direct work on PM-1, the portable reactor to be built for the Air Force at Sundance, Wyo. **Franklin G. Myers** succeeds Hittman as manager of the Reactor Systems dept. and Joseph V. Loppert succeeds Myers as operations manager of the division.

New employees at Nuclear Science and Engineering Corp. are: **Mahlon G. Young,** formerly of Abbott Laboratories, Oak Ridge, who has been named acting group leader in the chemistry dept.'s low-level radioactivity section; and **Alfred P. Intoccia,** graduate of the Univ. of Tenn., who has joined the biology and medicine dept. NSEC Director **Glenn T. Seaborg** of the Univ. of California has been appointed to President Eisenhower's Science Advisory Committee.

Harold Lambertus, nuclear fuels consultant, has been appointed manager of Spencer Chemical's Nuclear Fuels dept., succeeding **L. H. Landrum,** who resigned in March. Lambertus was instrumental in establishing the fuel-fabrication program of National Lead Co. as vice-president of American Bearing Corp., a National Lead division.

Lambertus

Personnel appointments at Armour Research Foundation include: **Charles Terrell,** reactor-physics supervisor; **William McElroy,** reactor-operations supervisor; and **W. D. Brennan,** research physicist for solids.

New staffers at Radiation Applications, Inc., are **George Odian,** an organic chemist; **Jerome Goodman,** a polymer and radiation chemist; and **David Sahud,** a physical chemist.

Woodrow E. Johnson, formerly of the Bettis Laboratory, has been named director of projects, Westinghouse Atomic Power dept. Johnson will handle "over-all planning, scheduling, customer relations, cost control and coordination of work" on all commercial power-reactor projects.

Claude C. "Bud" Conners has been named construction manager of the Consumers Public Power District's Hallam reactor; builder is Atomics International. The first AI employee assigned to the Hallam site, Conners has been in AI's Sodium Reactor Experiment (SRE) program for AEC at Santa Susana, Calif. He has also been with Tracerlab and Hughes Aircraft.

Conners

Riggs Nucleonics has named **David**

Lawrence sales engineer for its nuclear instrumentation line. Lawrence was manager, Nuclear div., Gene French Co.

An engineer-administrator-salesman, **Ralph W. Deuster,** has been appointed European nuclear sales representative for Babcock & Wilcox, with headquarters in Brussels. He will represent the company in the European market and maintain liaison with Euratom. Since joining B&W in 1955 he has been a nuclear-systems specialist (sales) and assistant manager of the propositions and contracts dept.

Deuster

General Electric has appointed **James W. Nelson, Jr.,** to succeed **Lyman R. Fink** as manager of the X-Ray dept., Milwaukee. Nelson was manager of GE's Microwave Laboratory at Palo Alto, Calif.; Fink recently took over from **Francis K. McCune** as general manager of the Atomic Products div. Nelson has held various managerial assignments at GE since 1946.

Nelson

John Howard Rust, project director of MIT's Dept. of Food Technology, has been appointed head of the new Section on Nuclear Medicine at the School of Medicine, Univ. of Chicago (NU, May '59, 209).

Philip M. Harrigan has joined the Enrico Fermi Reactor project near Detroit as instrument engineer. Harrigan has directed instrumentation work for Atomic Power Development Associates at its Riverview, Mich., facility.

Douglas M. Fouquet has left GE's San Jose operation to join General Atomic div. of General Dynamics as manager of public relations and advertising.

Capt. James W. Barnett, Jr., Army Corps of Engineers, has joined the Corps's Eastern Ocean district, New York, as nuclear project officer; the district's major project is a portable reactor to be supplied by Alco Products for a Greenland site. Barnett was chief of research and development at the Nuclear Power Field Office, Ft. Belvoir, Va.

Irwin Zimet has been named executive assistant to president David H. Cogan of Victoreen Instrument Co. Zimet will work closely with Cogan on management of the company and will handle coordination between and among the parent firm, its West Coast div. (Jordan Electronics) and its subsidiaries (Kolux Corp. and Tullamore Electronics).

Zimet

David L. Hetrick has established a consultant organization under his name in nuclear-power technology, neutron physics, reactor dynamics, reactor safety and reactor theory. A former member of the Atomics International staff, his new address is Box 52, Canoga Park, Calif.

Nicholas C. Christofilos of the Lawrence Radiation Laboratory, Livermore, Calif., has been named consultant to Boeing Airplane Co. in the application of nuclear energy in power plants. He joins two other Livermore scientists as Boeing consultants—**John Foster** (controlled fusion), and **Walter Crandall** (theoretical physics).

Donalee L. Tabern, founder of Abbott Laboratories' radio-pharmaceuticals program, has retired after 33 years with the company.

The acting head of Argonne National Laboratory's Applied Mathematics div., **William F. Miller,** has been given the job after some eight months as acting director. The division provides consultation on mathematical problems for other ANL divisions, carries out method research, and answers mathematical problems for ANL scientists. He joined ANL in 1955. Another ANL staffer, **Bernard Blumenthal,** an associate metallurgist, has taken a leave of absence to join Belgium's Centre d'Etude de l'Energie for one-two years of plutonium work.

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NUCLEAR CALENDAR

June 8–11—American Rocket Society semiannual meeting, San Diego. Session on nuclear propulsion. Contact Stan Gunn, Rocketdyne, 6633 Canoga Park Ave., Canoga Park, Calif.

June 9–11—Conference on Safeguards for Radioactive Materials at Canisius College, Buffalo, N. Y. Co-sponsored by Canisius and N. Y. Dept. of Labor. Contact Herman A. Szymanski, Canisius, Buffalo.

June 15–17—Annual meeting of the American Nuclear Society, Gatlinburg, Tenn. Contact Octave J. DuTemple, John Crerar Library, 86 E. Randolph St., Chicago 1.

June 15–20—Congress on Nuclear Energy, sponsored by National Committee for Nuclear Research, Rome, Italy (*Palace of the Congresses*). Scheduled in conjunction with 6th International Exhibition on Electronics and Atomic Energy in Rome, June 15–July 5. Contact Evandro Benvenuti, via della Scrofa 14, Rome.

June 17–20—Annual Meeting of National Society of Professional Engineers, New York City (*Commodore*). Contact Kenneth E. Trombley, NSPE, 2029 K St., N.W., Washington, D. C.

June 18–20—Fourth Annual Meeting of Health Physics Society, Gatlinburg, Tenn. Contact G. T. Saunders, Kewaunee Mfg. Co., Adrian, Mich.

June 18–20—Society of Nuclear Medicine, Chicago (*Palmer House*). Paper abstracts due March 1 to Donald W. Petit, Univ. of Southern California, School of Medicine, 1200 N. State St., Los Angeles 33.

June 22–26—Annual Meeting, American Society for Testing Materials, Atlantic City. Symposium on reactors, rockets and missiles June 22. First of a series of forums on reactor-materials standards June 25. Contact ASTM, 1916 Race St., Phila. 3.

June 22–26—52nd Annual Meeting of Air Pollution Control Assn., Los Angeles (*Statler-Hilton*). Session on radiological aspects of air pollution. Contact Bob Barsky, APCA, 434 South San Pedro, Los Angeles.

June 24–26—2nd Nuclear Instrumentation Symposium, Idaho Falls, Idaho. Contact H. S. Kindler, Instrument Society of America, 313 Sixth Ave., Pittsburgh 22, Pa.

June 25—Conference on AEC report literature for librarians in charge of AEC depositories, Washington, D. C. Contact Technical Information Service, AEC, Washington 25.

July 6–11—Seminar on Training of Spe-

cialists in Peaceful Uses of Atomic Energy, Saclay, France. Contact A. I. Galagan, International Atomic Energy Agency, United Nations, N. Y., or IAEA, Vienna, Austria.

July 17—9th Annual International Conference on High Energy Nuclear Physics, International Union of Pure and Applied Physics, Moscow. Contact Robert E. Marshak, Univ. of Rochester, Rochester, N. Y.

Aug. 17–21—4th International Conference on Ionization Phenomena in Gases, Uppsala, Sweden. Program includes high-temperature plasmas and controlled fusion. Abstracts due June 15 (350 words). Contact Ake Nilsson, Institute of Physics, Uppsala.

Sept. 7–12—Conference on Application of Large Radiation Sources in Industry, with emphasis on chemical processing, Warsaw, Poland. Contact A. I. Galagan, IAEA, United Nations, N. Y., or IAEA, Vienna.

Sept. 13–18—National Meeting of American Chemical Society, Atlantic City, N. J. Contact ACS, 2 Park Ave., N. Y., N. Y.

Sept. 14–19—International Conference on High Energy Accelerators and Instrumentation. Contact CERN Conference Secretariat, Geneva 23, Switz.

Sept. 22–24—3rd Industrial Nuclear Technology Conference on nonpower applications of nuclear technology, cosponsored by Armour Research Foundation and NUCLEONICS, Chicago (*Morrison*). Contact Leonard Reiffel, ARF, 10 W. 35th St., Chicago 16, Ill.

Sept. 28–Oct. 1—National Power Conference, cosponsored by American Society of Mechanical Engineers and American Institute of Electrical Engineers, Kansas City (*Muehlebach*). Contact ASME or AIEE, 33 W. 39th St., N. Y., N. Y.

Sept. 28–Oct. 1—Ninth Annual Instrument Symposium and Research Equipment Exhibit, Bethesda, Md. (*National Institutes of Health*). Contact James B. Davis, NIH, Public Health Service, Bethesda 14.

Oct. 15–16—Radiation Effects Symposium of Glass Div., American Ceramic Society, Galen Hall, Pa. Contact Norbert Kreidl, Bausch and Lomb Optical Co., Rochester 2, N. Y.

Oct. 26–28—Third Conference on Analytical Chemistry in Nuclear Reactor Technology, Gatlinburg, Tenn. .Contact C. D. Susano, Oak Ridge National Laboratory, P. O. Box Y, Oak Ridge, Tenn. (papers), or Tom Woods, Mgr., Mountain View Hotel, Gatlinburg (accommodations).

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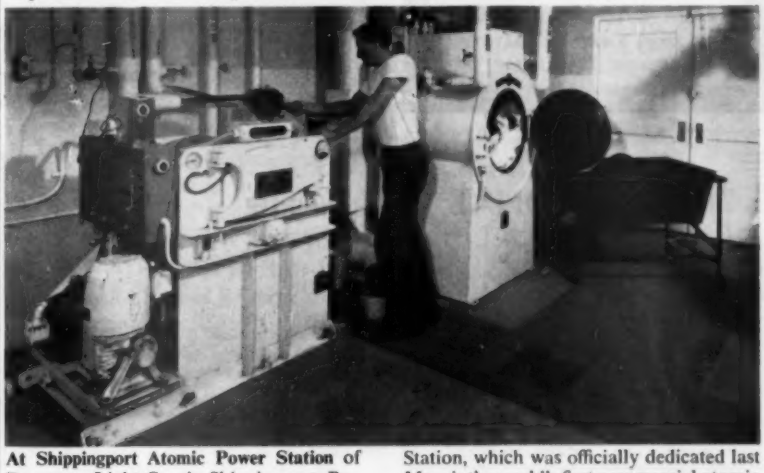

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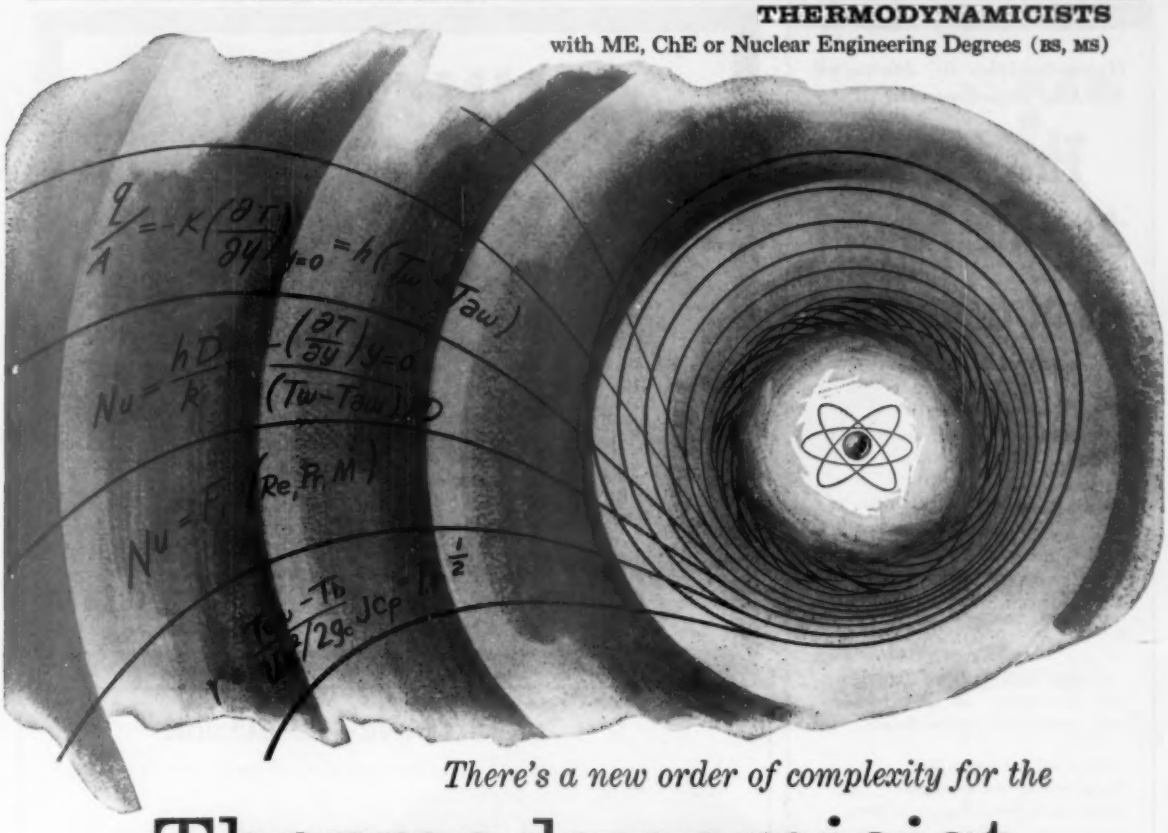

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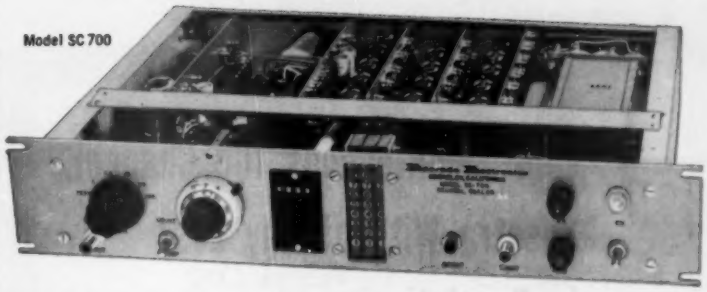

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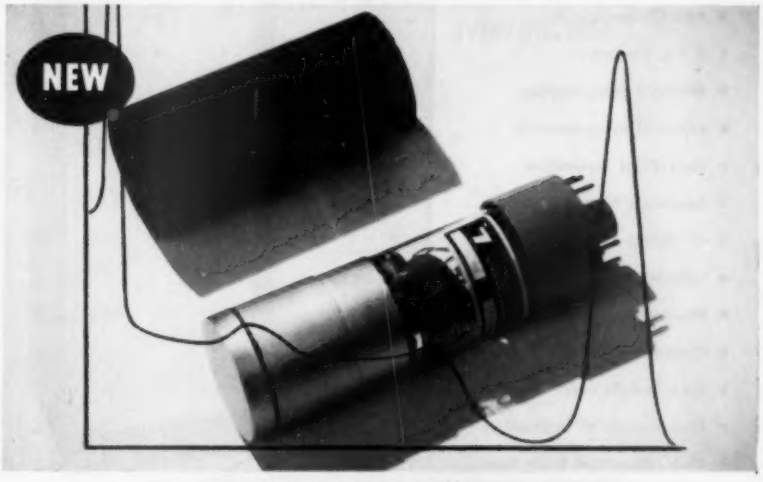

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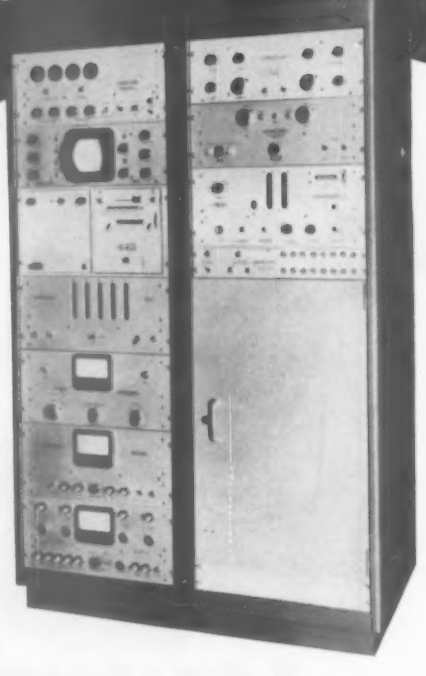

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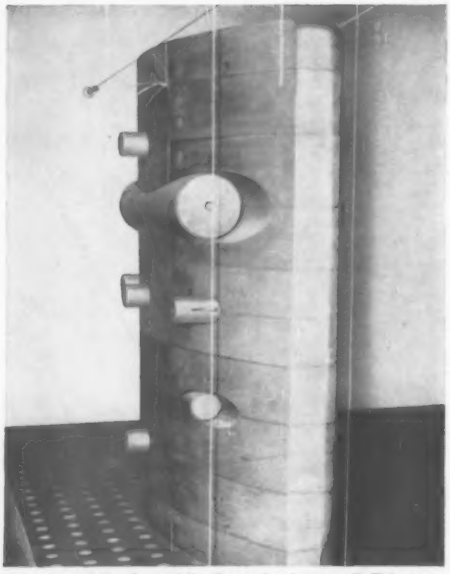
No. 1 eleven foot graphite thermal column wall of Atomic Energy of Canada Limited's NRU Reactor at Chalk River.



Side view of No. 1 graphite thermal column wall. This consists of 30 major blocks of "National" nuclear graphite contoured to fit into reactor tank. Machining characteristics of graphite have been compared to hard wood, such as oak or maple.

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